BRL

REPORT NO. 1237
JANUARY 1964

A MACHINE PROGRAM FOR COMPUTING NONLINEAR VISCOELASTIC WAVE PROPAGATION IN SOILS

Millicent M. Beck

RDT & E Project No. 1M010501A006

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

DDC AVAILABILITY NOTICE

Qualified requesters may obtain copies of this report from DDC.

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1237

JANUARY 1964

A MACHINE PROGRAM FOR COMPUTING NONLINEAR VISCOELASTIC WAVE PROPAGATION IN SOILS

Millicent M. Beck

Computing Laboratory

RDT & E Project No. 1M010501A006

A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1237

Millicent M. Beck/ilm
Aberdeen Proving Ground, Md.
January 1964

A MACHINE PROGRAM FOR COMPUTING NONLINEAR VISCOELASTIC WAVE PROPAGATION IN SOILS

ABSTRACT

A numerical method and its machine program for calculating nonlinear viscoelastic wave propagation in soils are described. Solutions give particle velocity, stress and strain as functions of time and distance from the stress source.

TABLE OF CONTENTS

TABLE OF SYMBOLS

Superscript

i	ith iteration.

Subscripts

m	index identifying the negative wave path characteristics (maximum value M).
n	index identifying the positive wave path characteristics (maximum value N).
o	initial state.

Roman

a, b	coefficients in the viscoelastic law (Equation II-4).
c	$\sqrt{\frac{\rho b}{a}}$
E	Young's modulus.
$f(\epsilon), g(\sigma)$	functions in the law defining the static stress - strain curve of a material (Equations II-5 and II-3).
F	$\frac{1}{a}\left[g(\sigma) - f(\epsilon)\right]$.
H, K	parameters in the static stress-strain law.
m	integer identifying the negative wave path characteristics.
n	integer identifying the positive wave path characteristics.
R, S	static constants of a material.
t	time.
Δt	time increment.
v	material velocity.
x	Lagrangian distance.

TABLE OF SYMBOLS (Cont'd)

Greek

$\left.\begin{matrix}\alpha\\ \beta\end{matrix}\right\}$	parameters in the static stress-strain law (Equation II-5).
δ	criterion for convergence.
ϵ	strain.
ρ	density of material.
σ	stress.
σ_o	initial stress.

I. INTRODUCTION

This report is primarily a reference to the BRLESC (Ballistic Research Laboratories' Electronic Scientific Computer) computational procedure used at the Ballistic Research Laboratories to solve a system of nonlinear differential equations describing the viscoelastic propagation of stress waves in soils.

Studies of this nature have been pursued in the past. Seismic forces and their associated motion have been measured under known conditions to check theoretical development[1,2,3*]. Simulation techniques have been used for the longer duration pulses produced by nuclear explosions. Measurements in the free field have shown that more consideration should be given to the phenomena occurring after the first stress peak. In order to evaluate theory on the diffraction of stress waves around an enclosure, a simple structure has been buried in a soil filled shock tube. The techniques are being improved for measurements of the required parameters associated with stress propagation.

When a nuclear device is detonated in air near the ground, a large area of the ground under the point of detonation is loaded nearly simultaneously. Under such loading, a uniform or horizontally layered half space would experience motion nearly perpendicular to the surface. Plane wave theory can be used to predict with sufficient accuracy the ground parameters near the surface which is close to the point under the detonation.

Since in the high stress region, we cannot use available linear elastic theory, nonlinear stress-strain assumptions must be made. Mercado[4,5,6] assumed a nonlinear viscoelastic theory (time dependent) which has been shown to be present under some extreme conditions. The quantitative importance of time dependency has not yet been established for the phenomena of interest here, and this effect may not be of major concern for many materials.

This work is a theoretical phase of the contract on propagation of underground shock waves contracted to Rensselaer Polytechnic Institute by the Terminal Ballistic Laboratory at Ballistic Research Laboratories.

Information obtained from such stress-wave studies are required for free field predictions and will be useful in the development of techniques for destroying or protecting underground structures from nuclear blast.

---

[*] Superscript numbers denote references listed at the end of this report.

II. THEORY

The theory discussed here is that of Mercado[4,5,6] which is based on Malvern's theory[7,8] for stress propagation in strain-rate sensitive materials.

An analytical representation of the stress-strain curve is obtained by fitting an empirical formula suggested by Osgood[9] of the form (Reference 4, Equation 2)

$$\epsilon = \frac{\sigma}{E} + R\left(\frac{\sigma}{E}\right)^{S} \tag{II-1}$$

to the static data. In the above equation ϵ = strain, σ = stress, E = Young's modulus and R and S are static constants of a material. With this law, the basic constitutive equation defining the material (Reference 4, Equation 10) takes the form

$$\sigma_t - \frac{b}{a}\,\epsilon_t = \frac{1}{a}\left[\epsilon - g(\sigma)\right], \tag{II-2}$$

where t represents time, a and b are coefficients in the viscoelastic law, and we choose

$$g(\sigma) = \frac{\sigma}{E} + K\left(\frac{\sigma}{E}\right)^{H}, \tag{II-3}$$

where H,K are parameters in the stress-strain law. Mercado states that there is no experimental data known from which the dynamic constants a and b may be directly determined[10]. It is known from theory that $b/a \geq E$, therefore, b/a is arbitrarily chosen. The lowest order approximation to the dynamic stress-strain law is obtained by truncating the time-wise expansions of σ and ϵ after the first derivative, giving

$$g(\sigma) + a\,\sigma_t = f(\epsilon) + b\epsilon_t, \tag{II-4}$$

where we arbitrarily choose

$$f(\epsilon) = \epsilon\,\frac{1 + \beta\epsilon}{1 + \alpha\epsilon}, \tag{II-5}$$

α and β being parameters in the stress-strain law.

The dynamic behavior of materials is obtained by simultaneous solution of the dynamic stress-strain law and the laws for the conservation of mass and momentum.

For a first approximation to the dynamic behavior of soils, we use the stress-strain law (II-4), the equation for the conservation of mass

(II-6) $$\epsilon_t = v_x,$$

and the equation for conservation of momentum

(II-7) $$\sigma_x = \rho v_t.$$

Here x is Lagrangian distance, v is material velocity, and ρ is density. Linear combinations of Equations II-4, II-6 and II-7 give the following set of characteristic equations. Along $\frac{dx}{dt} = 0$ (particle path),

(II-8) $$d\sigma - \frac{b}{a}\, d\epsilon = -\frac{1}{a}\left[g(\sigma) - f(\epsilon)\right] dt;$$

$$= -F(\sigma,\epsilon)dt$$

and along $\frac{dx}{dt} = \frac{b}{ac}$ (positive characteristic),

where

$$c \equiv \sqrt{\frac{\rho b}{a}}$$

and

$$F \equiv \frac{1}{a}\left[g(\sigma) - f(\epsilon)\right]$$

(II-9) $$d\sigma - c\, dv = -\frac{1}{a}\left[g(\sigma) - f(\epsilon)\right] dt$$

$$= -F(\sigma,\epsilon)dt;$$

and along $\frac{dx}{dt} = -\frac{b}{ac}$ (negative characteristic),

(II-10) $$d\sigma + c\, dv = -\frac{1}{a}\left[g(\sigma) - f(\epsilon)\right] dt$$

$$= -F(\sigma,\epsilon)dt.$$

These equations are supplemented by the jump conditions for a discontinuous wave propagating into a stationary medium in which $\sigma = 0$, $\epsilon = 0$ and $v = 0$. By replacing σ, ϵ, and v respectively in (II-4), (II-6), (II-7) by $\sigma H(\xi)$, $\epsilon H(\xi)$, and $vH(\xi)$, where $H(\xi) = 0$ for $\xi < 0$ and $H(\xi) = 1$ for $\xi > 0$ and $\frac{dH(\xi)}{d\xi}$ = Dirac δ, we integrate the results with respect to ξ from $-\xi$ to $+\xi$, and letting $\xi \to 0$ we obtain the jump relationship

$$\sigma = -cv = \frac{b}{a}\epsilon. \tag{II-11}$$

These equations represent the conservation of mass and momentum across a discontiuity moving into an undisturbed medium with the velocity

$$\frac{dx}{dt} = \frac{b}{ac}, \tag{II-12}$$

which is also a positive characteristic.

III. NUMERICAL FORMULATION

To compute the stress, strain, and particle velocity behind the wave front, we integrate the conservation equations using the known values along the wave front and the initial and boundary values.

The characteristic curves are used as the coordinate system to extend the solution into the domain of disturbance.

Using a grid of characteristics in the t,x plane (Figure 1) σ, ϵ, and v are evaluated at each point (m,n).

Along the wave front (m = 0), (II-9) and (II-11) hold. Differentiating Equation II-11 with respect to t and substituting into Equation II-9, we obtain

$$\frac{d\sigma}{dt} = \frac{1}{2a} g(\sigma) - f(\epsilon) = -\frac{1}{2} F(\sigma,\epsilon). \tag{III-1}$$

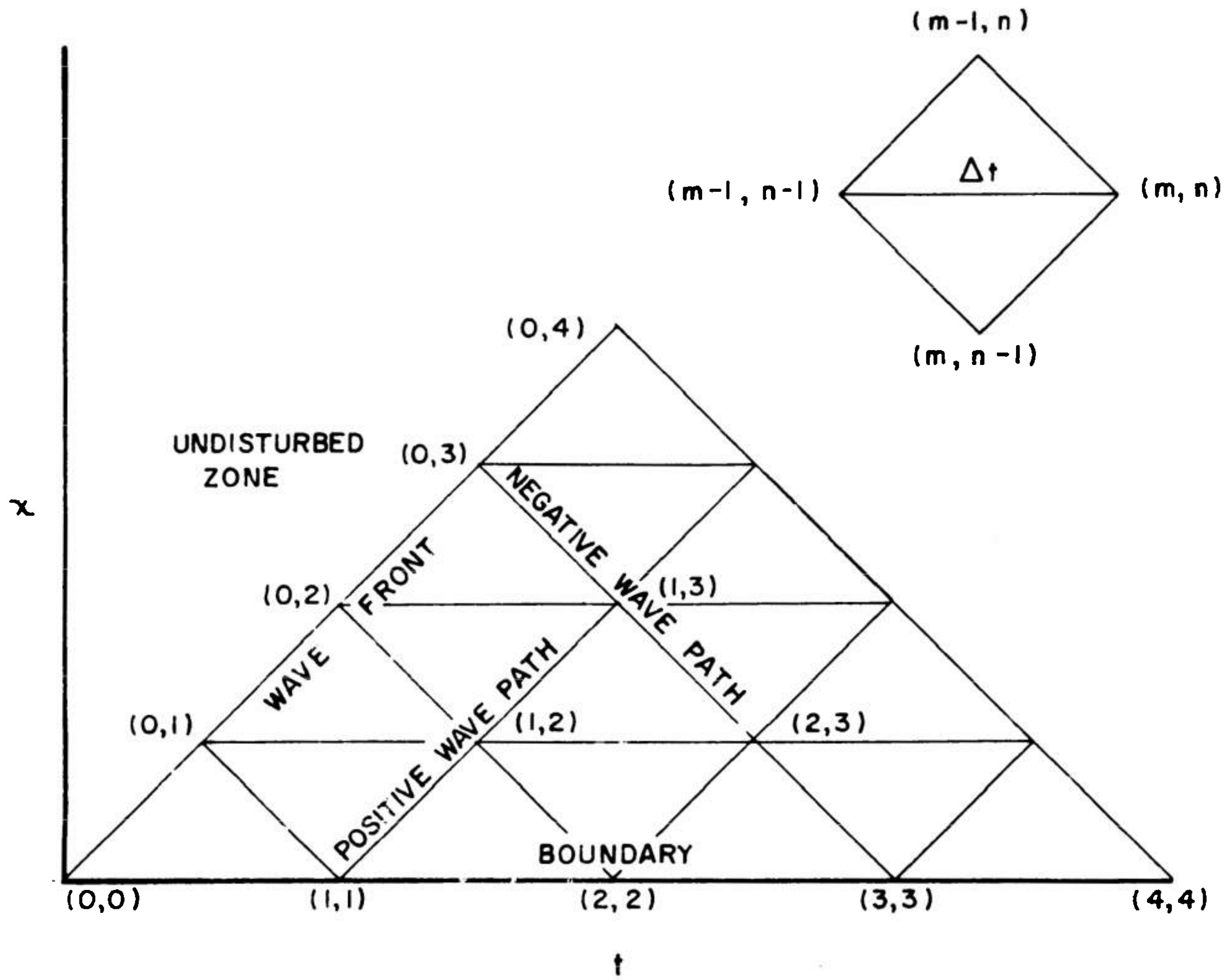

(m-1, n)
Δt
(m-1, n-1)
(m, n)
(m, n-1)
(0,4)
UNDISTURBED
ZONE
(0,3)
NEGATIVE WAVE PATH
FRONT
(0,2)
(1,3)
WAVE
POSITIVE WAVE PATH
(0,1)
(1,2)
(2,3)
BOUNDARY
(0,0)
(1,1)
(2,2)
(3,3)
(4,4)
x
t

FIGURE 1.

In difference form this equation becomes (see Figure 2)

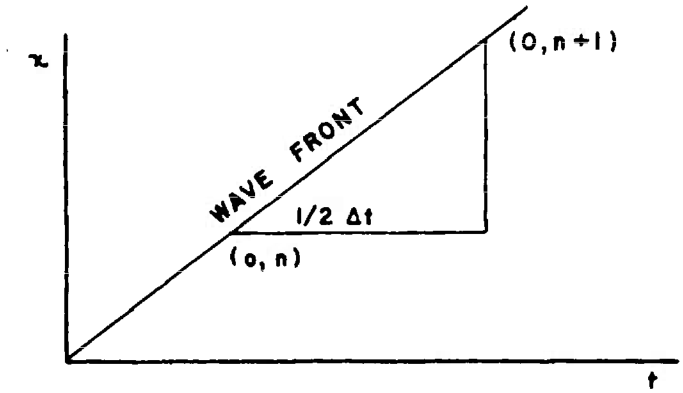


FIGURE 2.

$$(\text{III-2}) \qquad \frac{\sigma_{o,n+1} - \sigma_{o,n}}{\frac{1}{2}\,\Delta t} = - \frac{F\left(\overset{(i-1)}{\sigma}_{o,n+1},\ \overset{(i-1)}{\epsilon}_{o,n+1}\right) + F(\sigma_{o,n},\ \epsilon_{o,n})}{4}$$

or

$$(\text{III-3}) \qquad \overset{(i)}{\sigma}_{o,n+1} = \sigma_{o,n} - \frac{\Delta t}{8}\ f\left(\overset{(i-1)}{\sigma}_{o,n+1},\ \overset{(i-1)}{\epsilon}_{o,n+1}\right) + F(\sigma_{o,n},\ \epsilon_{o,n}).$$

With this value of σ at $(o,n+1)$, we have ϵ and v from (II-11).

$$(\text{III-4}) \qquad \overset{(i)}{\epsilon}_{o,n+1} = \frac{a}{b}\ \overset{(i)}{\sigma}_{o,n+1},$$

$$(\text{III-5}) \qquad \overset{(i)}{v}_{o,n+1} = -\frac{1}{c}\ \overset{(i)}{\sigma}_{o,n+1}.$$

Initially,

$$\sigma_{o,o} = \sigma_o,\ \epsilon_{o,o} = \frac{a}{b}\,\sigma_o$$

and

$$v_{o,o} = -\frac{1}{c}\,\sigma_o.$$

The set (III-3), (III-4), (III-5) are iterated over i at each point (o,n), until, for some arbitrarily small positive number δ,

$$\left| \frac{\sigma^{(i)} - \sigma^{(i-1)}}{\sigma^{(i-1)}} \right| < \delta, \tag{III-6}$$

n is then increased to some maximum value. Thus, the m = 0 characteristic is obtained.

For the m = 1 characteristic, the first point to be computed is the boundary point on the line x = 0. On this line we assume some constant value σ_o for the stress. Then the general boundary point (m,m) (see Figure 3), we compute as follows:

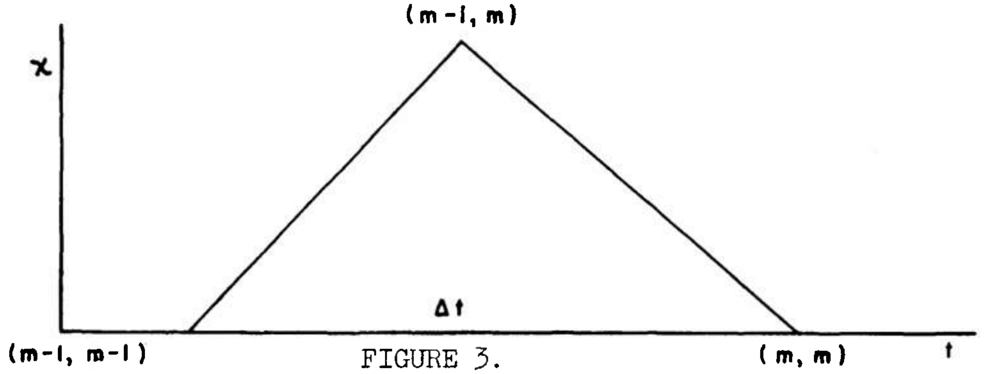


FIGURE 3.

The time and Lagrange distance are obtained from

$$t_{m,m} = t_{m-1,m-1} + \Delta t, \tag{III-7}$$

$$x_{m,m} = 0. \tag{III-8}$$

The stress is the specified value

$$\sigma_{m,m} = \sigma_o. \tag{III-9}$$

Let

$$\epsilon_{m,m}^{(o)} = \frac{\epsilon_{m-1,m-1} + \epsilon_{m-1,m}}{2}, \tag{III-10}$$

$$v_{m,m}^{(o)} = \frac{v_{m-1,m-1} + v_{m-1,m}}{2}. \tag{III-11}$$

The difference form of (II-8) gives for the strain

$$\text{(III-12)} \qquad \epsilon^{(i)}_{m,m} = \epsilon_{m-1,m-1} + \frac{a\Delta t}{b} \frac{f(\sigma_o, \epsilon_{m-1,m-1}) + F\left(\sigma_o, \epsilon^{(i-1)}_{m,m}\right)}{2},$$

and the difference form of (II-9) in which $d\sigma = 0$ gives for the velocity

$$\text{(III-13)} \qquad v^{(i)}_{m,m} = v_{m-1,m} - \frac{1}{c}(\sigma_o - \sigma_{m-1,m})$$

$$- \frac{\Delta t}{2c} \frac{F(\sigma_{m-1,m}, \epsilon_{m-1,m}) + F\left(\sigma_o, \epsilon^{(i-1)}_{m,m}\right)}{2}.$$

This process is repeated until for some i, the convergence test

$$\text{(III-14)} \qquad \left| \frac{\phi^{(i)}_{m,m} - \phi^{(i-1)}_{m,m}}{\phi^{(i-1)}_{m,m}} \right| < \delta$$

is satisfied, where $\phi = \epsilon$ and v, and where if the denominator is zero, this convergence test is bypassed.

With this boundary point computed, we progress up along the positive characteristic. Each point along this characteristic, say point (m,n) (see Figure 4), we compute as follows.

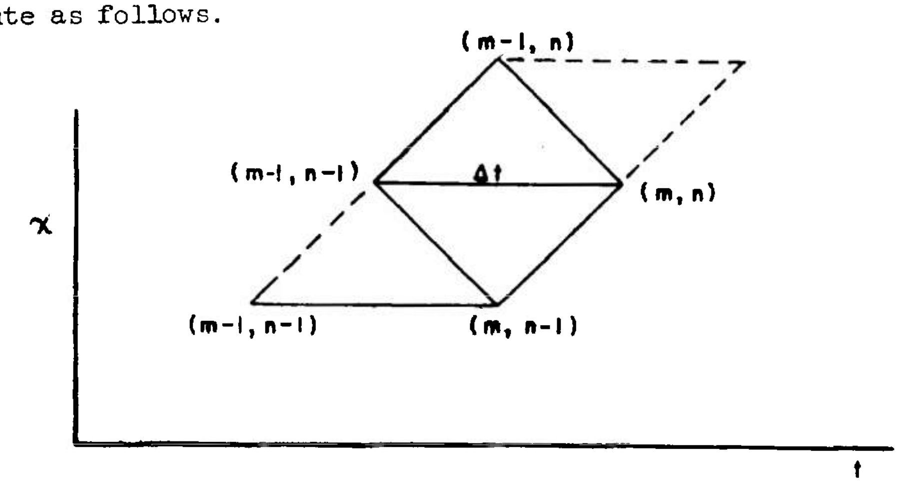


FIGURE 4.

The time and Lagrange distance are obtained from

(III-15) $$t_{m,n} = t_{m,n-1} + \frac{\Delta t}{2},$$

(III-16) $$x_{m,n} = x_{m,n-1} + \frac{b}{ac}\left(\frac{\Delta t}{2}\right).$$

Let

(III-17) $$\sigma^{(o)}_{m,n} = \frac{\sigma_{m-1,n} + \sigma_{m,n-1}}{2},$$

(III-18) $$\epsilon^{(o)}_{m,n} = \frac{\epsilon_{m-1,n} + \epsilon_{m,n-1}}{2},$$

(III-19) $$v^{(o)}_{m,n} = \frac{v_{m-1,n} + v_{m,n-1}}{2},$$

The difference forms of (II-8), (II-9), and (II-10) solved simultaneously give

(III-20) $$\sigma^{(i)}_{m,n} = \frac{\sigma_{m,n-1} + \sigma_{m-1,n}}{2} - \frac{c}{2}(v_{m,n-1} - v_{m-1,n}) - \frac{\Delta t}{4}\left[\frac{F(\sigma_{m,n-1}, \epsilon_{m,n-1}) + F\left(\sigma^{(i-1)}_{m,n}, \epsilon^{(i-1)}_{m,n}\right)}{2} + \frac{F(\sigma_{m-1,n}, \epsilon_{m-1,n}) + F\left(\sigma^{(i-1)}_{m,n}, \epsilon^{(i-1)}_{m,n}\right)}{2}\right],$$

(III-21) $$\epsilon^{(i)}_{m,n} = \epsilon_{m-1,n-1} + \frac{b\left(\sigma^{(i)}_{m,n} - \sigma_{m-1,n-1}\right)}{a} + \frac{\Delta t}{B}\,\frac{F(\sigma_{m-1,n-1}, \epsilon_{m-1,n-1}) + F\left(\sigma^{(i-1)}_{m,n}, \epsilon^{(i-1)}_{m,n}\right)}{2},$$

(III-22) $$v^{(i)}_{m,n} = v_{m,n-1} + \frac{\sigma^{(i)}_{m,n} - \sigma_{m,n-1}}{c} + \frac{\Delta t}{2c}\,\frac{F(\sigma_{m,n-1}, \epsilon_{m,n-1}) + F\left(\sigma^{(i-1)}_{m,n}, \epsilon^{(i-1)}_{m,n}\right)}{2}.$$

This process is repeated for each i until the convergence criterion

(III-23) $$\left[\frac{\phi^{(i)}_{m,n} - \phi^{(i-1)}_{m,n}}{\phi^{(i-1)}_{m,n}}\right] < \delta$$

is satisfied for $\phi = \sigma$, ϵ, and v.

IV. ORGANIZATION OF CALCULATION AND PROGRAM

For each m characteristic that we compute, we require values on the m-1 characteristic; therefore, the memory size limits the number of points that can be computed on each characteristic. In order not to limit the domain of computation, it was divided into zones. For this purpose, four codes are written, differing only in the input arrangements. These four codes can be used to cover the entire domain (Figure 5).

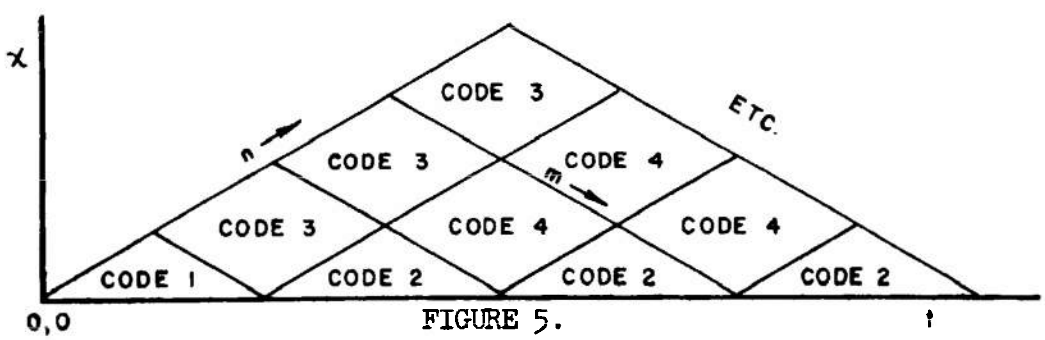


FIGURE 5.

An option provides a choice on the number of computed points to be printed. On the boundaries of each code zone, however, values at all points are printed, since they may be the input data for subsequent zones. Code 1 would suffice to complete the computation if the memory were sufficiently large to accommodate all the points on any given characteristic.

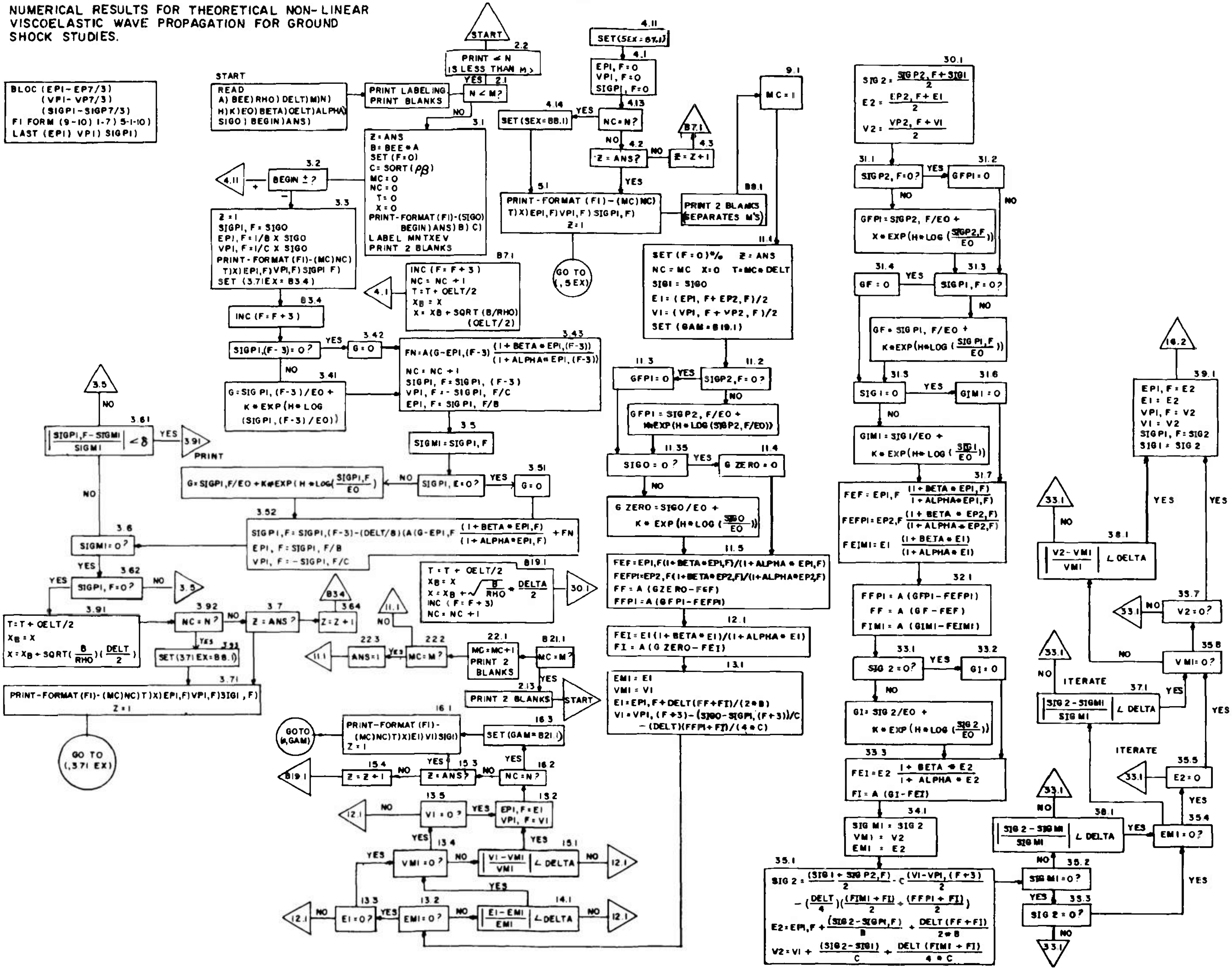
The compiler language used is the FORAST[11].

CODE SYMBOLS

CODE NAME	DEFINITIONS
A	$\frac{1}{a}$
ALPHA	α
ANS	Printing frequency (1,2,3,etc.)
B	$\frac{b}{a}$
BEE	b
BEGIN	{ + no shock at wave front { - shock at wave front
BETA	β
C	c
DELT	Δt
DELTA	δ
E	ϵ (strain)
EO	E (Young's modulus)
H	H
K	K
M	m
N	n
RHO	ρ
SIGMA	σ
SIGO	σ_o
T	t
V	v
X	x

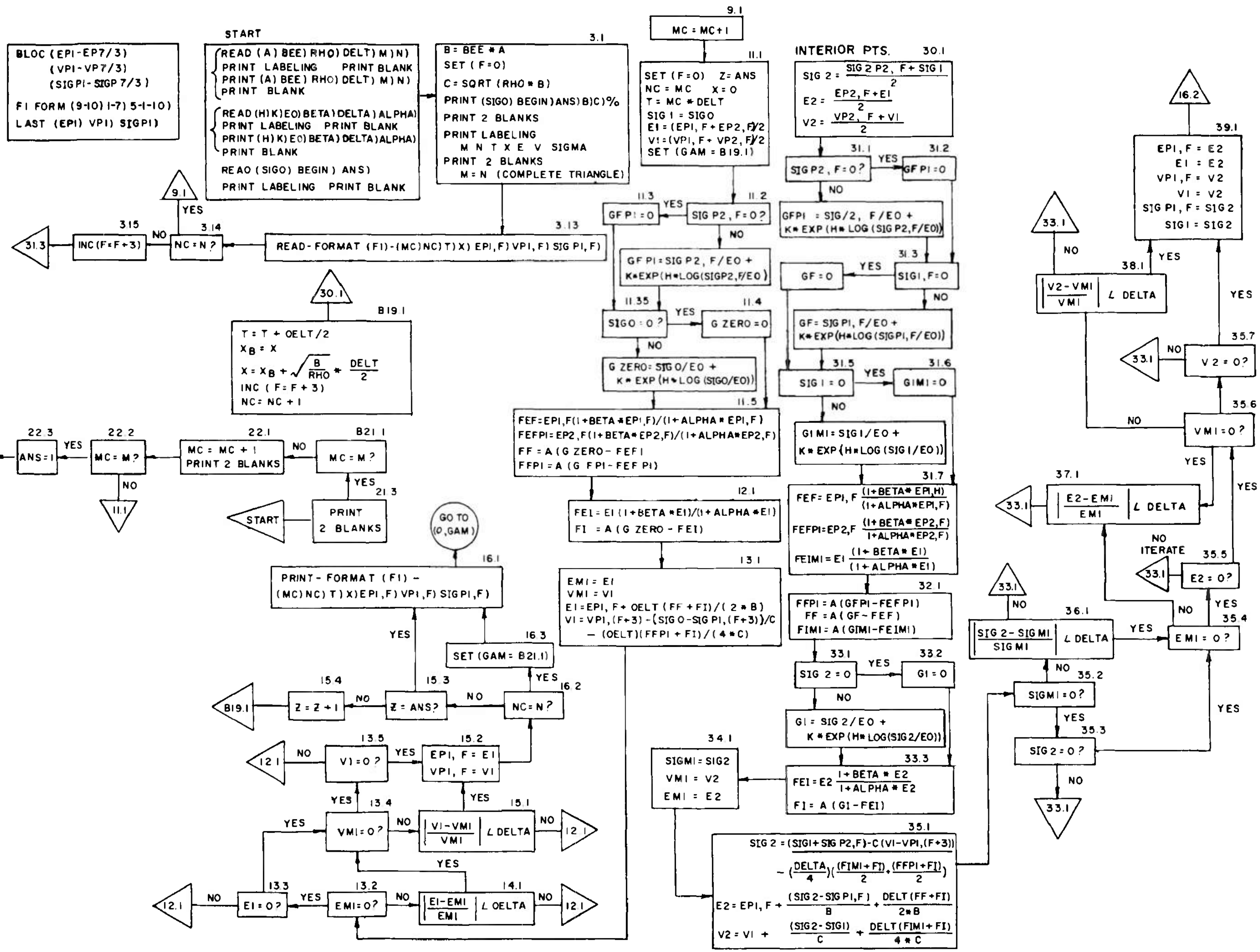
CODE I

NUMERICAL RESULTS FOR THEORETICAL NON-LINEAR VISCOELASTIC WAVE PROPAGATION FOR GROUND SHOCK STUDIES.



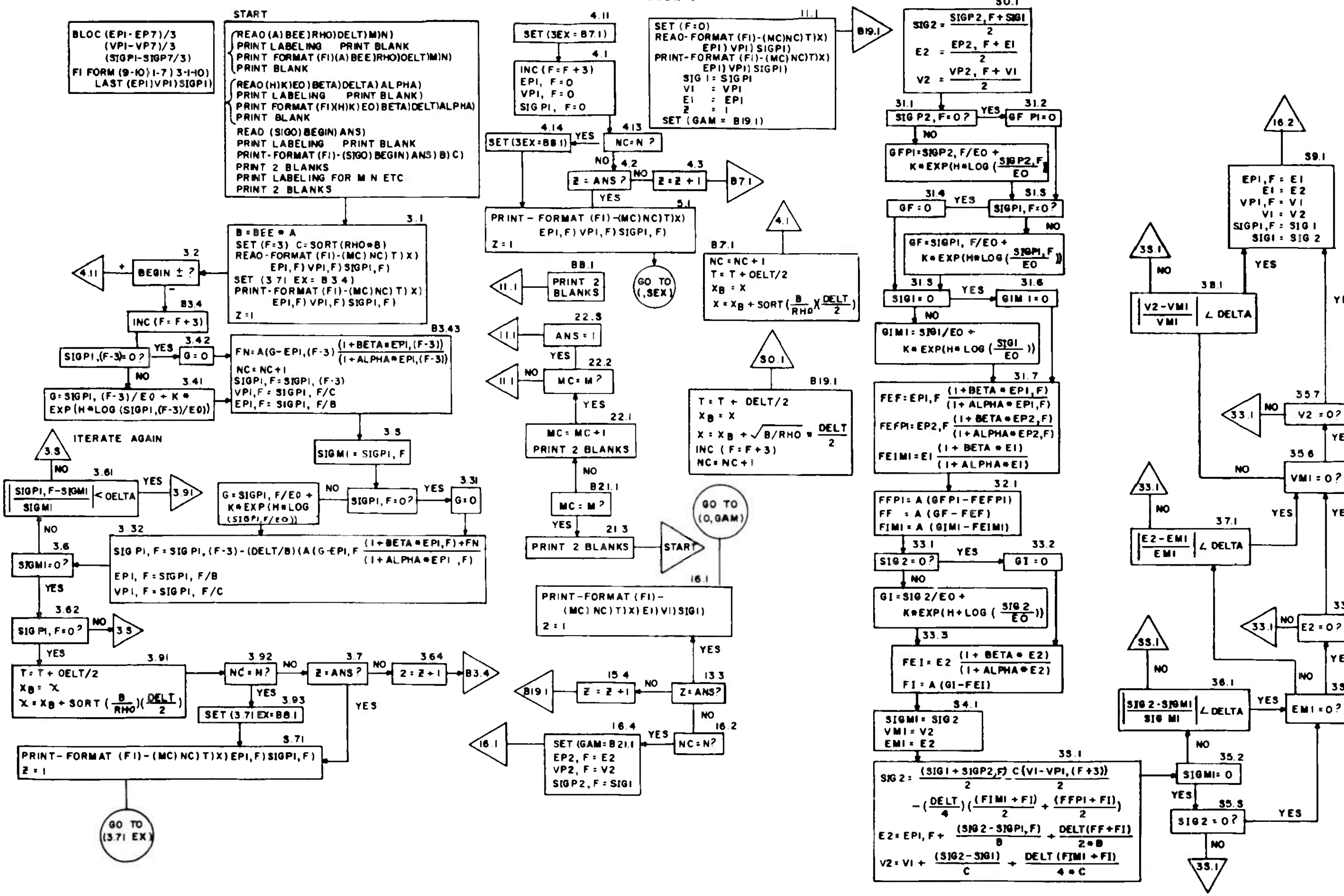
20

CODE 2



BLOC (EP1-EP7/3)
(VP1-VP7/3)
(SIGP1-SIGP7/3)
F1 FORM (9-10) 1-7) 5-1-10)
LAST (EP1) VP1) SIGP1)
START
READ (A) BEE) RHO) DELT) M) N)
PRINT LABELING PRINT BLANK
PRINT (A) BEE) RHO) DELT) M) N)
PRINT BLANK
READ (H) K) E0) BETA) DELTA) ALPHA)
PRINT LABELING PRINT BLANK
PRINT (H) K) E0) BETA) DELTA) ALPHA)
PRINT BLANK
READ (SIGO) BEGIN) ANS)
PRINT LABELING PRINT BLANK
3.1
B = BEE * A
SET (F=0)
C = SQRT (RHO * B)
PRINT (SIGO) BEGIN) ANS) B) C) %
PRINT 2 BLANKS
PRINT LABELING
M N T X E V SIGMA
PRINT 2 BLANKS
M=N (COMPLETE TRIANGLE)
9.1
MC = MC+1
11.1
SET (F=0) Z= ANS
NC = MC X=0
T = MC * DELT
SIG 1 = SIGO
E1 = (EP1, F + EP2, F)/2
V1 = (VP1, F + VP2, F)/2
SET (GAM = B19.1)
INTERIOR PTS. 30.1
SIG 2 = (SIG 2 P2, F + SIG 1)/2
E2 = (EP2, F + E1)/2
V2 = (VP2, F + V1)/2
31.1 SIG P2, F = 0? YES 31.2 GF P1 = 0
NO
GFP1 = SIG/2, F/E0 + K * EXP (H * LOG (SIG P2, F/E0))
31.3 SIG1, F = 0 YES GF = 0
NO
GF = SIG P1, F/E0 + K * EXP (H * LOG (SIG P1, F/E0))
31.5 SIG 1 = 0 YES 31.6 GIM1 = 0
NO
GIM1 = SIG1/E0 + K * EXP (H * LOG (SIG 1/E0))
31.7
FEF = EP1, F (1+BETA * EP1, H)/(1+ALPHA * EP1, F)
FEFP1 = EP2, F (1+BETA * EP2, F)/(1+ALPHA * EP2, F)
FEIM1 = E1 (1+BETA * E1)/(1+ALPHA * E1)
32.1
FFP1 = A (GFP1 - FEF P1)
FF = A (GF - FEF)
FIM1 = A (GIM1 - FEIM1)
33.1 SIG 2 = 0 YES 33.2 G1 = 0
NO
G1 = SIG 2/E0 + K * EXP (H * LOG (SIG 2/E0))
33.3
FE1 = E2 (1+BETA * E2)/(1+ALPHA * E2)
F1 = A (G1 - FE1)
34.1
SIGM1 = SIG2
VM1 = V2
EM1 = E2
35.1
SIG 2 = (SIG1 + SIG P2, F) - C (V1 - VP1, (F+3)) - (DELTA/4)((FIM1 + F1)/2 + (FFP1 + F1)/2)
E2 = EP1, F + (SIG 2 - SIG P1, F)/B + DELT (FF + F1)/(2 * B)
V2 = V1 + (SIG2 - SIG1)/C + DELT (FIM1 + F1)/(4 * C)
35.2 SIGM1 = 0? YES
35.3 SIG 2 = 0? NO 33.1 YES
36.1 |SIG 2 - SIG M1 / SIG M1| ∠ DELTA NO 33.1 YES
35.4 EM1 = 0? NO
37.1 |E2 - EM1 / EM1| ∠ DELTA 33.1
35.5 E2 = 0? NO ITERATE 33.1 YES
35.6 VM1 = 0? NO YES
38.1 |V2 - VM1 / VM1| ∠ DELTA NO 33.1 YES
35.7 V2 = 0? NO 33.1 YES
39.1
EP1, F = E2
E1 = E2
VP1, F = V2
V1 = V2
SIG P1, F = SIG 2
SIG1 = SIG2
16.2
11.2 SIG P2, F = 0? YES 11.3 GF P1 = 0
NO
GF P1 = SIG P2, F/E0 + K * EXP (H * LOG (SIGP2, F/E0))
11.35 SIGO = 0? YES 11.4 G ZERO = 0
NO
G ZERO = SIG O/E0 + K * EXP (H * LOG (SIGO/E0))
11.5
FEF = EP1, F (1+BETA * EP1, F)/(1+ALPHA * EP1, F)
FEFP1 = EP2, F (1+BETA * EP2, F)/(1+ALPHA * EP2, F)
FF = A (G ZERO - FEF1)
FFP1 = A (G FP1 - FEF P1)
12.1
FE1 = E1 (1+BETA * E1)/(1+ALPHA * E1)
F1 = A (G ZERO - FE1)
13.1
EM1 = E1
VM1 = V1
E1 = EP1, F + DELT (FF + F1)/(2 * B)
V1 = VP1, (F+3) - (SIG O - SIG P1, (F+3))/C - (DELT)(FFP1 + F1)/(4 * C)
3.13
READ-FORMAT (F1)-(MC) NC) T) X) EP1, F) VP1, F) SIG P1, F)
3.14 NC = N? YES 9.1 NO 3.15 INC (F=F+3) 31.3
30.1
B19.1
T = T + DELT/2
X_B = X
X = X_B + √(B/RHO) * DELT/2
INC (F = F+3)
NC = NC + 1
B21.1 MC = M? NO 22.1 MC = MC + 1 PRINT 2 BLANKS
22.2 MC = M? YES 22.3 ANS = 1 11.1
NO 11.1
YES 21.3 PRINT 2 BLANKS START
GO TO (0, GAM)
16.1
PRINT-FORMAT (F1) - (MC) NC) T) X) EP1, F) VP1, F) SIG P1, F)
16.3 SET (GAM = B21.1)
16.2 NC = N? YES NO
15.3 Z = ANS? YES NO 15.4 Z = Z+1 B19.1
13.5 V1 = 0? NO 12.1 YES
15.2 EP1, F = E1 VP1, F = V1
15.1 |V1 - VM1 / VM1| ∠ DELTA NO 12.1 YES
13.4 VM1 = 0? YES
14.1 |E1 - EM1 / EM1| ∠ DELTA NO 12.1 YES
13.2 EM1 = 0? NO YES
13.3 E1 = 0? NO 12.1 YES

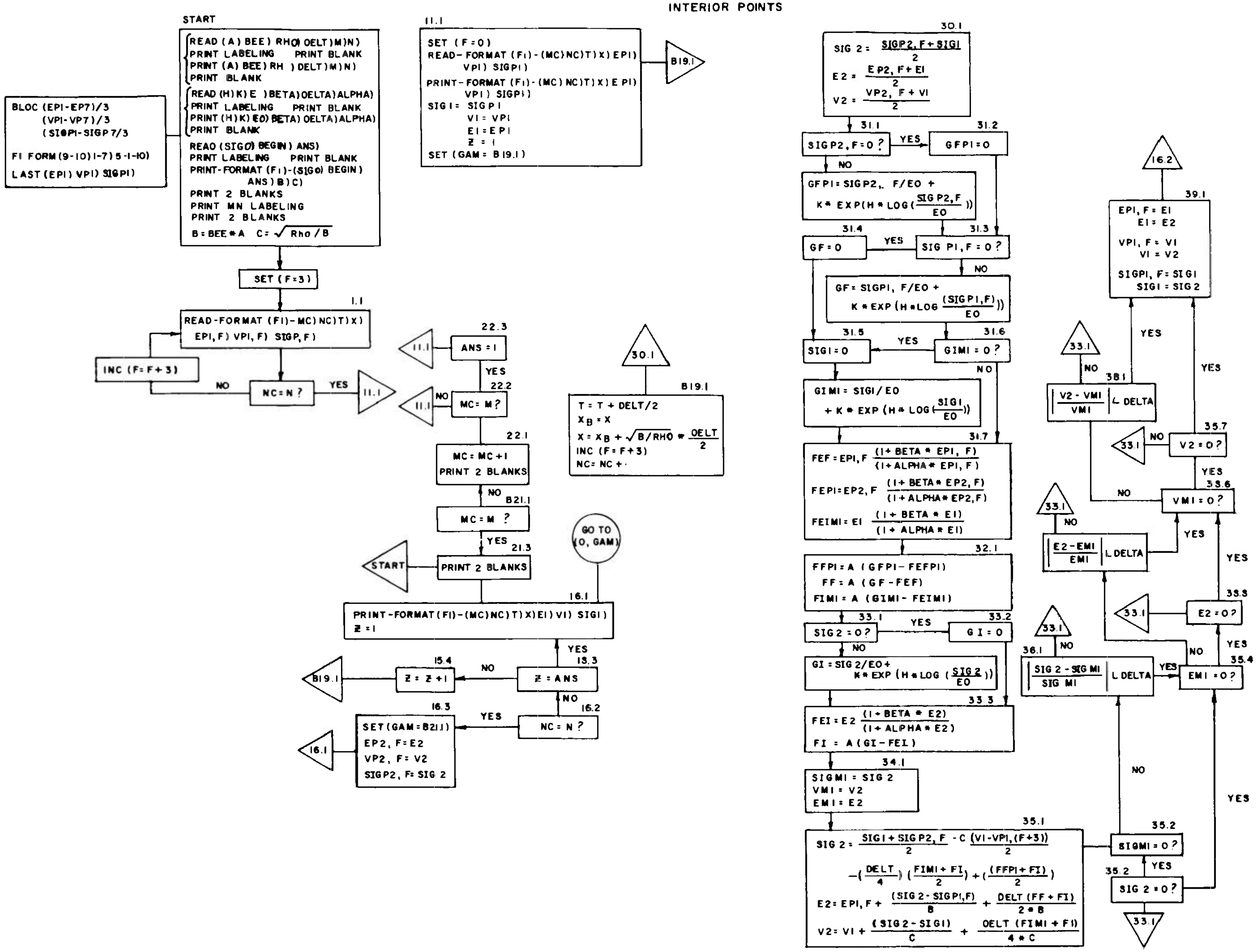
CODE 3



BLOC (EP1-EP7)/3
(VP1-VP7)/3
(SIGP1-SIGP7/3)
FI FORM (9-10) 1-7) 3-1-10)
LAST (EP1)VP1)SIGP1)
START
READ (A) BEE) RHO) DELT) M) N)
PRINT LABELING PRINT BLANK
PRINT FORMAT (FI)(A) BEE) RHO) DELT) M) N)
PRINT BLANK
READ (H) K) EO) BETA) DELTA) ALPHA)
PRINT LABELING PRINT BLANK)
PRINT FORMAT (FI)(H) K) EO) BETA) DELT) ALPHA)
PRINT BLANK
READ (SIGO) BEGIN) ANS)
PRINT LABELING PRINT BLANK
PRINT-FORMAT (FI)-(SIGO) BEGIN) ANS) B) C)
PRINT 2 BLANKS
PRINT LABELING FOR M N ETC
PRINT 2 BLANKS
3.1
B = BEE * A
SET (F=3) C=SORT(RHO*B)
READ-FORMAT (FI)-(MC) NC) T) X)
EP1, F) VP1, F) SIGP1, F)
SET (3.71 EX= B3.4)
PRINT-FORMAT (FI)-(MC) NC) T) X)
EP1, F) VP1, F) SIGP1, F)
Z = 1
3.2
BEGIN ± ?
4.11
B3.4
INC (F = F + 3)
3.42
SIGP1, (F-3) = 0 ?
YES
G = 0
NO
3.41
G = SIGP1, (F-3)/EO + K * EXP (H * LOG (SIGP1, (F-3)/EO))
B3.43
FN = A(G-EP1, (F-3) (1+BETA*EP1, (F-3))/(1+ALPHA*EP1, (F-3))
NC = NC + 1
SIGP1, F = SIGP1, (F-3)
VP1, F = SIGP1, F/C
EP1, F = SIGP1, F/B
3.5
SIGM1 = SIGP1, F
3.5
ITERATE AGAIN
NO
3.61
|SIGP1, F-SIGM1 / SIGM1| < DELTA
YES
3.91
G = SIGP1, F/EO + K * EXP (H * LOG (SIGP1, F/EO))
NO
SIGP1, F = 0 ?
YES
3.31
G = 0
3.32
SIGP1, F = SIGP1, (F-3) - (DELT/B) (A (G-EP1, F (1+BETA*EP1, F)/(1+ALPHA*EP1, F)) + FN
EP1, F = SIGP1, F/B
VP1, F = SIGP1, F/C
3.6
SIGM1 = 0 ?
YES
3.62
SIGP1, F = 0 ?
NO
3.5
YES
3.91
T = T + DELT/2
XB = X
X = XB + SORT (B/RHO)(DELT/2)
3.92
NC = N ?
NO
3.7
Z = ANS ?
NO
3.64
Z = Z + 1
B3.4
YES
3.93
SET (3.71 EX = B8.1)
YES
3.71
PRINT-FORMAT (FI)-(MC) NC) T) X) EP1, F) SIGP1, F)
Z = 1
GO TO (3.71 EX)
4.11
SET (3EX = B7.1)
4.1
INC (F = F + 3)
EP1, F = 0
VP1, F = 0
SIGP1, F = 0
4.14
SET (3EX = B8.1)
YES
4.13
NC = N ?
NO
4.2
Z = ANS ?
NO
4.3
Z = Z + 1
B7.1
YES
5.1
PRINT-FORMAT (FI)-(MC) NC) T) X)
EP1, F) VP1, F) SIGP1, F)
Z = 1
B8.1
11.1
PRINT 2 BLANKS
GO TO (, 3EX)
22.5
11.1
ANS = 1
YES
22.2
11.1
NO
MC = M ?
YES
22.1
MC = MC + 1
PRINT 2 BLANKS
NO
B21.1
MC = M ?
YES
21.3
PRINT 2 BLANKS
START
GO TO (0, GAM)
16.1
PRINT-FORMAT (FI)-
(MC) NC) T) X) E1) V1) SIG1)
Z = 1
YES
13.3
B19.1
15.4
Z = Z + 1
NO
Z = ANS ?
NO
16.2
16.1
16.4
SET (GAM: B21.1
EP2, F = E2
VP2, F = V2
SIGP2, F = SIG1
YES
NC = N ?
11.1
SET (F = 0)
READ-FORMAT (FI)-(MC) NC) T) X)
EP1) VP1) SIGP1)
PRINT-FORMAT (FI)-(MC) NC) T) X)
EP1) VP1) SIGP1)
SIG 1 = SIGP1
V1 = VP1
E1 = EP1
Z = 1
SET (GAM = B19.1)
B19.1
4.1
B7.1
NC = NC + 1
T = T + DELT/2
XB = X
X = XB + SORT (B/RHO)(DELT/2)
50.1
B19.1
T = T + DELT/2
XB = X
X = XB + √(B/RHO) * DELT/2
INC (F = F + 3)
NC = NC + 1
50.1
SIG2 = (SIGP2, F + SIG1)/2
E2 = (EP2, F + E1)/2
V2 = (VP2, F + V1)/2
31.1
SIGP2, F = 0 ?
YES
31.2
GFP1 = 0
NO
GFP1 = SIGP2, F/EO + K * EXP(H * LOG (SIGP2, F/EO))
31.4
GF = 0
YES
31.5
SIGP1, F = 0 ?
NO
GF = SIGP1, F/EO + K * EXP(H * LOG (SIGP1, F/EO))
31.5
SIG1 = 0
YES
31.6
GIM1 = 0
NO
GIM1 = SIG1/EO + K * EXP(H * LOG (SIG1/EO))
31.7
FEF = EP1, F (1+BETA*EP1, F)/(1+ALPHA*EP1, F)
FEFP1 = EP2, F (1+BETA*EP2, F)/(1+ALPHA*EP2, F)
FEIM1 = E1 (1+BETA*E1)/(1+ALPHA*E1)
32.1
FFP1 = A (GFP1 - FEFP1)
FF = A (GF - FEF)
FIM1 = A (GIM1 - FEIM1)
33.1
SIG2 = 0 ?
YES
33.2
G1 = 0
NO
G1 = SIG2/EO + K * EXP(H * LOG (SIG2/EO))
33.3
FE1 = E2 (1+BETA*E2)/(1+ALPHA*E2)
F1 = A (G1 - FE1)
34.1
SIGM1 = SIG2
VM1 = V2
EM1 = E2
35.1
SIG2 = (SIG1 + SIGP2, F)/2 - C(V1 - VP1, (F+3))/2
- (DELT/4)((FIM1 + F1)/2 + (FFP1 + F1)/2)
E2 = EP1, F + (SIG2 - SIGP1, F)/B + DELT(FF + F1)/(2*B)
V2 = V1 + (SIG2 - SIG1)/C + DELT (FIM1 + F1)/(4*C)
35.2
SIGM1 = 0
YES
35.5
SIG2 = 0 ?
NO
33.1
YES
16.2
39.1
EP1, F = E1
E1 = E2
VP1, F = V1
V1 = V2
SIGP1, F = SIG1
SIG1 = SIG2
YES
33.1
NO
38.1
|V2 - VM1 / VM1| < DELTA
YES
35.7
33.1
NO
V2 = 0 ?
YES
35.6
NO
VM1 = 0 ?
YES
33.1
NO
37.1
|E2 - EM1 / EM1| < DELTA
YES
35.5
33.1
NO
E2 = 0 ?
YES
33.1
NO
36.1
|SIG2 - SIGM1 / SIGM1| < DELTA
YES
NO
35.4
EM1 = 0 ?
NO
YES

CODE 4

INTERIOR POINTS



23

PROGRAM FOR CODE I AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

```
        PROB  TF-033  GROUND  SHOCK  STUDIES   CODE 1
        BLOC(EPI-EP7/3)VP1-VP7/3)SIGPI-SIGP7/3)%
F1      FORM(9-10)1-7)5-1-10)%
        LAST(EP1)VP1)SIGP1)%
START       READ(A)BEE)RHO)DELT)M)N)%
            PRINT-FORMAT(F1)-
        CONT     <     A          BEE        RHO      DELT       >
        CONT<    M            N         >% ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%
            READ(H)K)EO)BETA)DELTA)ALPHA)%
            PRINT-FORMAT(F1)-
        CONT     <     H          K          EO       BETA       >
        CONT<DELTA      ALPHA       >%ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%
            READ(SIGO)BEGIN)ANS)%
            PRINT-FORMAT(F1)-
        CONT      < SIGO       BEGIN      ANS          B          C      >%
            ENTER(PRINTB)%
2.1         IF(N<M)GOTO(2.2)%
3.1         B=BEE*A%  T=0%X=0%
            Z=ANS%
            SET(F=0)%C=SQRT(RHO*B   )%MC=0%NC=0%
            PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%
            ENTER(PRINTB)%  ENTER(PRINTB)%
            PRINT-FORMAT(F1)-
        CONT     <     M          N          T          X          E       >
        CONT < V          SIGMA      >%
            ENTER(PRINTB)%ENTER(PRINTB)%
3.2         IF(BEGIN)IS+GOTO(4.11)%
3.3         SIGP1,F=SIGO%EP1,F=SIGO/B%VP1,F=-SIGO/C%
            Z=1%  SET(3.71EX=B3.4)%
            PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
B3.4        INC(F=F+3)%
            IF(SIGP1,(F-3) =0)GOTO(3.42)%
3.41        G=SIGP1,(F-3)
        CONT              /EO+K*EXP(H*LOG(SIGP1,(F-3)/EO))%GOTO(3.43)%
3.42        G=0%
3.43        FN=A(G-EP1,(F-3)(1+BETA*EP1,(F-3))/(1+ALPHA*EP1,(F-3)))%
            NC=NC+1%SIGPI,F=SIGP1,(F-3)%
            VP1,F=-SIGP1,F/C%EP1,F=SIGP1,F/B%
3.5         SIGM1=SIGP1,F%
            IF(SIGP1,F    =0)GOTO(3.51)%
            G=SIGP1,F/EO+K*EXP(H*LOG(SIGP1,F     /EO))%GOTO(3.52)%
3.51        G=0%
3.52        SIGP1,F=SIGP1,(F-3)-(DELT/8)(A(G-EP1,F(1+BETA*EP1,F)/
        CONT(1+ALPHA*EP1,F))+FN)%
            EP1,F=SIGP1,F/B%VP1,F=-SIGP1,F/C%
3.6         IF(SIGM1=0)GOTO(3.62)%
3.61        IF-ABS((SIGP1,F-SIGM1)/SIGM1<DELTA)GOTO(3.91)%GOTO(3.5)%
3.62        IF(SIGP1,F=0)GOTO(3.91)%GOTO(3.5)%
3.71        PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
            Z=1%  GOTO(,3.71EX)%
3.91        T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%
3.92        IF(NC=N)WITHIN(.005)GOTO(3.93)%
```

```
3.7       IF(Z=ANS)WITHIN(.005)GOTO(3.71)%
3.64      Z=Z+1%    GOTO(B3.4)%
3.93      SET(3.71EX=B8.1)%GOTO(3.71)%
4.11      SET(5EX=B7.1)%
4.1       EP1,F=0%VP1,F=0%SIGP1,F=0%
4.13      IF(NC=N)WITHIN(.005)GOTO(4.14)%
4.2       IF(Z=ANS)WITHIN(.005)GOTO(5.1)%
4.3       Z=Z+1%     GOTO(B7.1)%
4.14      SET(5EX=B8.1)%
5.1       PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
          Z=1%    GOTO(,5EX)%
B7.1      INC(F=F+3)%NC=NC+1%T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%
          GOTO(4.1)%
B8.1      ENTER(PRINTB)%ENTER(PRINTB)%
9.1           MC=1%
11.1      SET(F=0)% NC=MC%X=0%T=MC*DELT%
          Z=ANS%        SET(GAM=B19.1)%
          SIG1=SIGO%E1=(EP1,F+EP2,F)/2%V1=(VP1,F+VP2,F)/2%
11.2      IF(SIGP2,F    =0)GOTO(11.3)%
          GFP1=SIGP2,F/EO+K*EXP(H*LOG(SIGP2,F/EO))%GOTO(11.35)%
11.3      GFP1=0%
11.35     IF(SIGO    =0)GOTO(11.4)%
          GZERO=SIGO/EO+K*EXP(H*LOG(SIGO/EO))%GOTO(11.5)%
11.4      GZERO=0%
11.5      FEF=EP1,F(1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
          FEFP1=EP2,F(1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
          FF=A(GZERO-FEF)%
          FFP1=A(GFP1-FEFP1)%
12.1      FEI=E1(1+BETA*E1)/(1+ALPHA*E1)%
          FI=A(GZERO-FEI)%
13.1      EM1=E1%VM1=V1%
          E1=EP1,F+DELT(FF+FI)/(2*B)%
          V1=VP1,(F+3)-(SIGO-SIGP1,(F+3))/C-(DELT)(FFP1+FI)/(4*C)%
13.2      IF(EM1=0)GOTO(13.3)%
14.1      IF-ABS((E1-EM1)/EM1<DELTA)GOTO(13.4)%GOTO(12.1)%
13.3      IF(E1=0)GOTO(13.4)%GOTO(12.1)%
13.4      IF(VM1=0)GOTO(13.5)%
15.1      IF-ABS((V1-VM1)/VM1<DELTA)GOTO(15.2)%GOTO(12.1)%
13.5      IF(V1=0)GOTO(15.2)%GOTO(12.1)%
15.2      EP1,F=E1%VP1,F=V1%
16.2      IF(NC=N)GOTO(16.3)%
15.3      IF(Z=ANS)WITHIN(.005)GOTO(16.1)%
15.4      Z=Z+1%    GOTO(B19.1)%
16.1      PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%
          Z=1%    GOTO(C,GAM)%
16.3      SET(GAM=821.1)%  GOTO(16.1)%
B19.1                              INC(F=F+3)%NC=NC+1%
          T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%GOTO(30.1)%
B21.1     IF(MC=M)WITHIN(.005)GOTO(21.3)%
22.1      MC=MC+1%  ENTER(PRINTB)% ENTER(PRINTB)%
22.2      IF(MC=M)WITHIN(.005)GOTO(22.3)%  GOTO(11.1)%
22.3      ANS=1% GOTO(11.1)%
21.3      ENTER(PRINTB)%  ENTER(PRINTB)%  GOTO(START)%
30.1      SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%
          V2=(VP2,F+V1)/2%
31.1      IF(SIGP2,F =0)GOTO(31.2)%
          GFP1=SIGP2,F/EO+K*EXP(H*LOG(SIGP2,F/EO))%GOTO(31.3)%
31.2      GFP1=0%
```

```
31.3      IF(SIGP1,F    =0)GOTO(31.4)%
          GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%
31.4      GF=0%
31.5      IF(SIG1    =0)GOTO(31.6)%
          GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%
31.6      GIM1=0%
31.7      FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
          FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
          FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%
32.1      FFP1=A(GFP1-FEFP1)%  FF=A(GF-FEF)%
          FIM1=A(GIM1-FEIM1)%
33.1      IF(SIG2    =0)GOTO(33.2)%
          GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%
33.2      GI=0%
33.3      FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%
          FI=A(GI-FEI)%
34.1      SIGM1=SIG2%VM1=V2%EM1=E2%
35.1      SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2
       CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%
          E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%
          V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%
35.2      IF(SIGM1=0)GOTO(35.3)%
36.1      IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%
35.3      IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%
35.4      IF(EM1=0)GOTO(35.5)%
37.1      IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%
35.5      IF(E2=0)GOTO(35.6)%GOTO(33.1)%
35.6      IF(VM1=0)GOTO(35.7)%
38.1      IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%
35.7      IF(V2=0)GOTO(39.1)%GOTO(33.1)%
39.1      EP1,F=E2%E1=E2% VP1,F=V2%V1=V2%
          SIGP1,F=SIG2%SIG1=SIG2%GOTO(16.2)%
2.2       PRINT<    N        IS       LESS      THAN        M      >%
          ENTER(PRINTB)% ENTER(PRINTB)%  GOTO(START)%
       END GOTO(START)%

CASE 1      10X10 DOMAIN          INPUT PARAMETERS

      A            BEE           RHO          DELT             M             N
 90388944 07 23896900-02 15000000-03 20000000-03 10000000 02 10000000 02
      H             K            E0           BETA         DELTA         ALPHA
 22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
    SIGO         BEGIN          ANS
 50000000 02-50000000 00 10000000 01

CASE 2      3X3  ZONE             INPUT PARAMETERS

      A            BEE           RHO          DELT             M             N
 90388944 07 23896900-02 15000000-03 20000000-03 30000000 01 30000000 01
      H             K            E0           BETA         DELTA         ALPHA
 22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
    SIGO         BEGIN          ANS
 50000000 02-50000000 00 10000000 01
```

PROGRAM FOR CODE 2 AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

```
        PROB  TF-033  GROUND  SHOCK  STUDIES  CODE2
        BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%
F1      FORM(9-10)1-7)5-1-10)%
        LAST(EP1)VP1)SIGP1)%
START      READ(A)BEE)RHO)DELT)M)N)%
           PRINT-FORMAT(F1)-
        CONT     <     A         BEE        RHO      DELT       >
        CONT<    M           N       >% ENTER(PRINTB)%
           PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%
           READ(H)K)E0)BETA)DELTA)ALPHA)%
           PRINT-FORMAT(F1)-
        CONT     <     H          K          E0        BETA     >
        CONT<DELTA       ALPHA       >%ENTER(PRINTB)%
           PRINT-FORMAT(F1)-(H)K)E0)BETA)DELTA)ALPHA)%ENTER(PRINTB)%
           READ(SIGO)BEGIN)ANS)%
           PRINT-FORMAT(F1)-
        CONT      < SIGO       BEGIN      ANS          B            C      >%
           ENTER(PRINTB)%
3.1        B=BEE*A%
           SET(F=0)%C=SQRT(RHO*B  )%
           PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%
           ENTER(PRINTB)%  ENTER(PRINTB)%
           PRINT-FORMAT(F1)-
        CONT      <     M          N            T          X           E        >
        CONT < V         SIGMA      >%
           ENTER(PRINTB)%ENTER(PRINTB)%  M=N%
3.13       READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
3.14       IF(NC=N)WITHIN(.005)GOTO(9.1)%
3.15       INC(F=F+3)%             GOTO(3.13)%
9.1        MC=MC+1%
11.1       SET(F=0)% NC=MC%X=0%T=MC*DELT%
           Z=ANS%     SET(GAM=B19.1)%
           SIG1=SIGO%E1=(EP1,F+EP2,F)/2%V1=(VP1,F+VP2,F)/2%
11.2       IF(SIGP2,F    =0)GOTO(11.3)%
           GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(11.35)%
11.3       GFP1=0%
11.35      IF(SIGO    =0)GOTO(11.4)%
           GZERO=SIGO/E0+K*EXP(H*LOG(SIGO/E0))%GOTO(11.5)%
11.4       GZERO=0%
11.5       FEF=EP1,F(1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
           FEFP1=EP2,F(1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
           FF=A(GZERO-FEF)%
           FFP1=A(GFP1-FEFP1)%
12.1       FEI=E1(1+BETA*E1)/(1+ALPHA*E1)%
           FI=A(GZERO-FEI)%
13.1       EM1=E1%VM1=V1%
           E1=EP1,F+DELT(FF+FI)/(2*B)%
           V1=VP1,(F+3)-(SIGO-SIGP1,(F+3))/C-(DELT)(FFP1+FI)/(4*C)%
13.2       IF(EM1=0)GOTO(13.3)%
14.1       IF-ABS((E1-EM1)/EM1<DELTA)GOTO(13.4)%GOTO(12.1)%
13.3       IF(E1=0)GOTO(13.4)%GOTO(12.1)%
13.4       IF(VM1=0)GOTO(13.5)%GOTO(15.1)%
15.1       IF-ABS((V1-VM1)/VM1<DELTA)GOTO(15.2)%GOTO(12.1)%
13.5       IF(V1=0)GOTO(15.2)%GOTO(12.1)%
```

```
15.2     EP1,F=E1%VP1,F=V1%
16.2     IF(NC=N)WITHIN(.005)GOTO(16.3)%
15.3     IF(Z=ANS)WITHIN(.005)GOTO(16.1)%
15.4     Z=Z+1% GOTO(B19.1)%
16.1     PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%
         Z=1%  GOTO(0,GAM)%
16.3     SET(GAM=B21.1)%   GOTO(16.1)%
B19.1                        INC(F=F+3)%NC=NC+1%
         T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%GOTO(30.1)%
B21.1    IF(MC=M)WITHIN(.005)GOTO(21.3)% MC=MC+1%   ENTER(PRINTB)%
         ENTER(PRINTB)% IF(MC=M)WITHIN(.005)GOTO(22.3)% GOTO(11.1)%
21.3     ENTER(PRINTB)%  ENTER(PRINTB)%  GOTO(START)%
22.3     ANS=1% GOTO(11.1)%
30.1     SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%
         V2=(VP2,F+V1)/2%
31.1     IF(SIGP2,F =0)GOTO(31.2)%
         GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%
31.2     GFP1=0%
31.3     IF(SIGP1,F    =0)GOTO(31.4)%
         GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%
31.4     GF=0%
31.5     IF(SIG1    =0)GOTO(31.6)%
         GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%
31.6     GIM1=0%
31.7     FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
         FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
         FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%
32.1     FFP1=A(GFP1-FEFP1)%  FF=A(GF-FEF)%
         FIM1=A(GIM1-FEIM1)%
33.1     IF(SIG2    =0)GOTO(33.2)%
         GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%
33.2     GI=0%
33.3     FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%
         FI=A(GI-FEI)%
34.1     SIGM1=SIG2%VM1=V2%EM1=E2%
35.1     SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2
      CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%
         E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%
         V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%
35.2     IF(SIGM1=0)GOTO(35.3)%
36.1     IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%
35.3     IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%
35.4     IF(EM1=0)GOTO(35.5)%
37.1     IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%
35.5     IF(E2=0)GOTO(35.6)%GOTO(33.1)%
35.6     IF(VM1=0)GOTO(35.7)%
38.1     IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%
35.7     IF(V2=0)GOTO(39.1)%GOTO(33.1)%
39.1     EP1,F=E2%E1=E2% VP1,F=V2%V1=V2%
         SIGP1,F=SIG2%SIG1=SIG2%GOTO(16.2)%
      END GOTO(START)%
```

CASE 1 INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944 07	23896900-02	15000000-03	20000000-03	40000000 01	70000000 01

```
      H              K              EO            BETA          DELTA          ALPHA
 22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
    SIGO          BEGIN          ANS
 50000000 02-50000000 00 10000000 01
```

INPUT BOUNDARY DATA ON M=3 CHARACTERISTIC

```
     M          N          T          X          E          V        SIGMA
 300000 01 300000 01 600000-03 000000 00 451328-02-383640 02 500000 02
 300000 01 400000 01 700000-03 120000 01 412734-02-359208 02 477472 02
 300000 01 500000 01 800000-03 240001 01 379712-02-337303 02 456285 02
 300000 01 600000 01 900000-03 360001 01 351191-02-317622 02 436460 02
 300000 01 700000 01 100000-02 480002 01 326356-02-299895 02 417963 02
```

CASE 2   INPUT PARAMETERS

```
      A             BEE            RHO           DELT             M              N
 90388944 07 23896900-02 15000000-03 20000000-03 80000000 01 10000000 02
      H              K              EO            BETA          DELTA          ALPHA
 22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
    SIGO          BEGIN          ANS
 50000000 02-50000000 00 10000000 01
```

INPUT BOUNDARY DATA ON M=7 CHARACTERISTIC

```
 700000 01 700000 01 140000-02 000000 00 670435-02-459084 02 500000 02
 700000 01 800000 01 150000-02 120000 01 623943-02-438848 02 487296 02
 700000 01 900000 01 160000-02 240001 01 582185-02-419527 02 474410 02
 700000 01 100000 02 170000-02 360001 01 544555-02-401182 02 461515 02
```

PROGRAM FOR CODE 3 AND INPUT PARAMETERS WITH BOUNDARY DATA FOR A SPECIAL CASE

```
        PROB  TF-033  GROUND  SHOCK  STUDIES          CODE 3
        BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%
F1      FORM(9-10)1-7)5-1-10)%
        LAST(EP1)VP1)SIGP1)%
START       READ(A)BEE)RHO)DELT)M)N)%
            PRINT-FORMAT(F1)-
        CONT      <     A          BEE         RHO       DELT       >
        CONT<     M           N         >% ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%
            READ(H)K)FO)BETA)DELTA)ALPHA)%
            PRINT-FORMAT(F1)-
        CONT      <     H          K           EO        BETA       >
        CONT<DELTA      ALPHA      >%ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%
            READ(SIGO)BEGIN)ANS)%
            PRINT-FORMAT(F1)-
        CONT      < SIGO       BEGIN       ANS        >%   ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)%ENTER(PRINTB)%ENTER(PRINTB)%
            PRINT-FORMAT(F1)-
        CONT      <     M          N           T          X          E       >
        CONT < V           SIGMA      >%
            ENTER(PRINTB)%ENTER(PRINTB)%
3.1         B=BEE*A%
            SET(F=3)%C=SQRT(RHO*B  )%
            READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
            PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
            Z=1%  SET(3.71EX=B3.4)%
3.2         IF(BEGIN)IS+GOTO(4.11)%
B3.4        INC(F=F+3)%
            IF(SIGP1,(F-3) =0)GOTO(3.42)%
3.41        G=SIGP1,(F-3)
        CONT              /EO+K*EXP(H*LOG(SIGP1,(F-3)/EO))%GOTO(3.43)%
3.42        G=0%
3.43        FN=A(G-EP1,(F-3)(1+BETA*EP1,(F-3))/(1+ALPHA*EP1,(F-3)))%
            NC=NC+1%SIGP1,F=SIGP1,(F-3)%
            VP1,F=-SIGP1,F/C%EP1,F=SIGP1,F/B%
3.5         SIGM1=SIGP1,F%
            IF(SIGP1,F    =0)GOTO(3.51)%
            G=SIGP1,F/EO+K*EXP(H*LOG(SIGP1,F     /EO))%GOTO(3.52)%
3.51        G=0%
3.52        SIGP1,F=SIGP1,(F-3)-(DELT/8)(A(G-EP1,F(1+BETA*EP1,F)/
        CONT(1+ALPHA*EP1,F))+FN)%
            EP1,F=SIGP1,F/B%VP1,F=-SIGP1,F/C%
3.6         IF(SIGM1=0)GOTO(3.62)%
3.61        IF-ABS((SIGP1,F-SIGM1)/SIGM1<DELTA)GOTO(3.91)%GOTO(3.5)%
3.62        IF(SIGP1,F=0)GOTO(3.91)%GOTO(3.5)%
3.91        T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%
3.92        IF(NC=N)WITHIN(.005)GOTO(3.93)%
3.7         IF(Z=ANS)WITHIN(.005)GOTO(3.71)%
3.64        Z=Z+1%    GOTO(B3.4)%
3.71        PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
            Z=1%  GOTO(,3.71EX)%
3.93        SET(3.71EX=B8.1)%GOTO(3.71)%
4.11        SET(5EX=B7.1)%
```

```
4.1        INC(F=F+3)%
           EP1,F=0%VP1,F=0%SIGP1,F=0%
4.13       IF(NC=N)WITHIN(.005)GOTO(4.14)%
4.2        IF(Z=ANS)WITHIN(.005)GOTO(5.1)%
4.3        Z=Z+1%    GOTO(B7.1)%
4.14       SET(5EX=B8.1)%
5.1        PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
           Z=1%   GOTO(,5EX)%
B7.1                     NC=NC+1%T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%
           GOTO(4.11)%
B8.1       ENTER(PRINTB)%ENTER(PRINTB)%  GOTO(11.1)%
11.1       SET(F=0)%
           READ-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%
           PRINT-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%
           SIG1=SIGP1%   V1=VP1%   E1=EP1%   Z=1%
           SET(GAM=B19.1)%
B19.1                           INC(F=F+3)%NC=NC+1%
           T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%
30.1       SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%
           V2=(VP2,F+V1)/2%
31.1       IF(SIGP2,F  =0)GOTO(31.2)%
           GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%
31.2       GFP1=0%
31.3       IF(SIGP1,F   =0)GOTO(31.4)%
           GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%
31.4       GF=0%
31.5       IF(SIG1    =0)GOTO(31.6)%
           GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%
31.6       GIM1=0%
31.7       FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
           FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
           FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%
32.1       FFP1=A(GFP1-FEFP1)%  FF=A(GF-FEF)%
           FIM1=A(GIM1-FEIM1)%
33.1       IF(SIG2   =0)GOTO(33.2)%
           GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%
33.2       GI=0%
33.3       FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%
           FI=A(GI-FEI)%
34.1       SIGM1=SIG2%VM1=V2%EM1=E2%
35.1       SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2
       CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%
           E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%
           V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%
35.2       IF(SIGM1=0)GOTO(35.3)%
36.1       IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%
35.4       IF(EM1=0)GOTO(35.5)%
37.1       IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%
35.5       IF(E2=0)GOTO(35.6)%GOTO(33.1)%
35.6       IF(VM1=0)GOTO(35.7)%
38.1       IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%
35.7       IF(V2=0)GOTO(39.1)%GOTO(33.1)%
35.3       IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%
39.1       EP1,F=E1%   E1=E2%  VP1,F=V1%   V1=V2%
           SIGP1,F=SIG1%   SIG1=SIG2%   GOTO(16.2)%
B21.1      IF(MC=M)WITHIN(.005)GOTO(21.3)%
22.1       MC=MC+1%  ENTER(PRINTB)% ENTER(PRINTB)%
22.2       IF(MC=M)WITHIN(.005)GOTO(22.3)%  GOTO(11.1)%
```

```
22.3       ANS=1% GOTO(11.1)%
21.3       ENTER(PRINTB)%  ENTER(PRINTB)%  GOTO(START)%
16.2       IF(NC=N)GOTO(16.3)%
15.3       IF(Z=ANS)WITHIN(.005)GOTO(16.1)%
15.4       Z=Z+1%    GOTO(B19.1)%
16.1       PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%
           Z=1%    GOTO(0,GAM)%
16.3       SET(GAM=B21.1)%  EP2,F=E2%  VP2,F=V2%  SIGP2,F=SIG2%
           GOTO(16.1)%
       END GOTO(START)%
```

INPUT PARAMETERS

```
     A           BEE          RHO          DELT             M            N
 90388944 07 23896900-02 15000000-03 20000000-03 30000000 01 10000000 02
     H            K            E0          BETA         DELTA        ALPHA
 22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
   SIGO        BEGIN         ANS
 50000000 02-50000000 00 10000000 01
```

INPUT BOUNDARY DATA ON N=3 CHARACTERISTIC

```
 000000 00 300000 01 300000-03 360001 01 183368-02-220043 02 396079 02
 100000 01 300000 01 400000-03 240001 01 260629-02-275758 02 438797 02
 200000 01 300000 01 500000-03 120000 01 350227-02-330727 02 473202 02
 300000 01 300000 01 600000-03 000000 00 451328-02-383640 02 500000 02
```

PROGRAM FOR CODE 4 AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

```
        PROB  TF-033  GROUND  SHOCK  STUDIES         CODE 4
        BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%
F1      FORM(9-10)1-7)5-1-10)%
        LAST(EP1)VP1)SIGP1)%
START       READ(A)BEE)RHO)DELT)M)N)%
            PRINT-FORMAT(F1)-
        CONT     <     A         BEE       RHO      DELT       >
        CONT<    M          N       >% ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%
            READ(H)K)E0)BETA)DELTA)ALPHA)%
            PRINT-FORMAT(F1)-
        CONT     <     H           K          E0        BETA     >
        CONT<DELTA       ALPHA      >%ENTER(PRINTB)%
            PRINT-FORMAT(F1)-(H)K)E0)BETA)DELTA)ALPHA)%ENTER(PRINTB)%
            READ(SIGO)BEGIN)ANS)%
            PRINT-FORMAT(F1)-
        CONT     < SIGO      BEGIN     ANS          B           C     >%
            ENTER(PRINTB)%
            B=BEE*A%    C=SQRT(RHO*B)%
            PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%
            ENTER(PRINTB)%  ENTER(PRINTB)%
            PRINT-FORMAT(F1)-
        CONT     <     M           N          T          X          E        >
        CONT < V         SIGMA      >%
            ENTER(PRINTB)%ENTER(PRINTB)%
            SET(F=3)%
1.1         READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%
            IF(NC=N)WITHIN(.005)GOTO(11.1)% INC(F=F+3)%  GOTO(1.1)%
11.1        SET(F=0)%  READ-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%
            PRINT-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%  SET(GAM=B19.1)%
            SIG1=SIGP1%  V1=VP1%  E1=EP1% Z=1% GOTO(B19.1)%
B19.1                            INC(F=F+3)%NC=NC+1%
            T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%GOTO(30.1)%
16.2        IF(NC=N)WITHIN(.005)GOTO(16.3)%
15.3        IF(Z=ANS)WITHIN(.005)GOTO(16.1)%
15.4        Z=Z+1%    GOTO(B19.1)%
16.1        PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%
            Z=I%   GOTO(0,GAM)%
16.3        SET(GAM=B21.1)% EP2,F=E2% VP2,F=V2% SIGP2,F=SIG2% GOTO(16.1)%
B21.1       IF(MC=M)WITHIN(.005)GOTO(21.3)%
22.1        MC=MC+1%  ENTER(PRINTB)% ENTER(PRINTB)%
22.2        IF(MC=M)WITHIN(.005)GOTO(22.3)%  GOTO(11.1)%
22.3        ANS=1% GOTO(11.1)%
21.3        ENTER(PRINTB)% ENTER(PRINTB)%  GOTO(START)%
30.1        SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%
            V2=(VP2,F+V1)/2%
31.1        IF(SIGP2,F  =0)GOTO(31.2)%
            GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%
31.2        GFP1=0%
31.3        IF(SIGP1,F    =0)GOTO(31.4)%
            GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%
31.4        GF=0%
31.5        IF(SIG1    =0)GOTO(31.6)%
            GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%
```

```
31.6        GIM1=0%
31.7        FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%
            FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%
            FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%
32.1        FFP1=A(GFP1-FEFP1)%  FF=A(GF-FEF)%
            FIM1=A(GIM1-FEIM1)%
33.1        IF(SIG2   =0)GOTO(33.2)%
            GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%
33.2        GI=0%
33.3        FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%
            FI=A(GI-FEI)%
34.1        SIGM1=SIG2%VM1=V2%EM1=E2%
35.1        SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2
        CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%
            E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%
            V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%
35.2        IF(SIGM1=0)GOTO(35.3)%GOTO(36.1)%
35.3        IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%
35.4        IF(EM1=0)GOTO(35.5)%GOTO(37.1)%
35.5        IF(E2=0)GOTO(35.6)%GOTO(33.1)%
36.1        IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%
37.1        IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%
35.6        IF(VM1=0)GOTO(35.7)%GOTO(38.1)%
35.7        IF(V2=0)GOTO(39.1)%GOTO(33.1)%
38.1        IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%
39.1        EP1,F=E1%E1=E2% VP1,F=V1%V1=V2%
            SIGP1,F=SIG1%SIG1=SIG2%GOTO(16.2)%
        END GOTO(START)%
```

INPUT PARAMETERS

```
     A             BEE            RHO           DELT             M              N
90388944 07 23896900-02 15000000-03 20000000-03 70000000 01 10000000 02
     H              K             E0            BETA          DELTA          ALPHA
22200000 01 68600000 04 21400000 05 00000000 00 10000000-08 00000000 00
   SIGO          BEGIN           ANS
50000000 02-50000000 00 10000000 01
```

INPUT BOUNDARY DATA ON M=3 CHARACTERISTIC

```
300000 01 700000 01 100000-02 480002 01 326356-02-299895 02 417963 02
300000 01 800000 01 110000-02 600002 01 304572-02-283882 02 400730 02
300000 01 900000 01 120000-02 720003 01 285339-02-269371 02 384683 02
300000 01 100000 02 130000-02 840003 01 268255-02-256182 02 369738 02
```

INPUT BOUNDARY DATA ON N=7 CHARACTERISTIC

```
400000 01 700000 01 110000-02 360001 01 402989-02-342221 02 444541 02
500000 01 700000 01 120000-02 240001 01 486855-02-383498 02 467066 02
600000 01 700000 01 130000-02 120000 01 576599-02-422768 02 485524 02
700000 01 700000 01 140000-02 000000 00 670435-02-459084 02 500000 02
```

V. RESULTS

An example is computed on a grid of maximum m = maximum n = 10, both by use of code 1 and by use of the set of codes 1,2,3,4 (Figure 6).

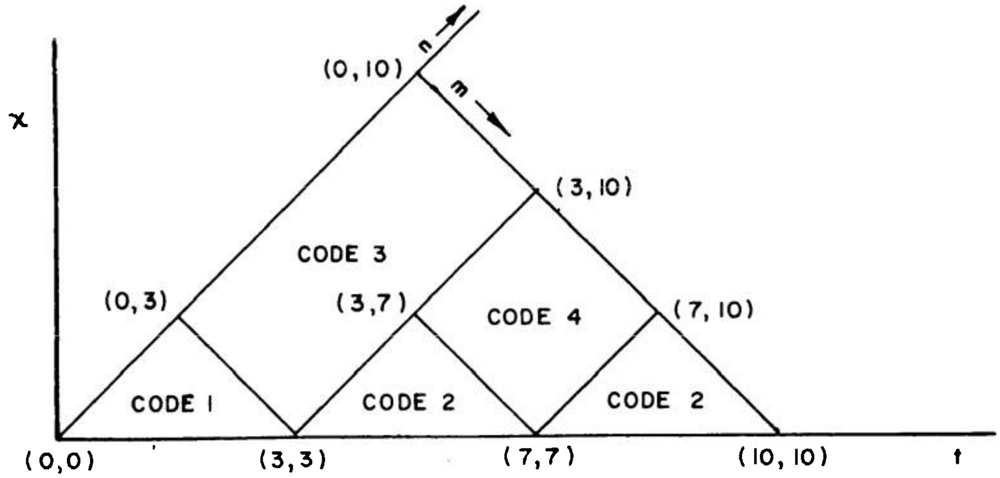


FIGURE 6

Code 1 uses data along the wave front and boundary; code 2 uses data along the smallest m of its zone and along the boundary; code 3 uses wave front data and data along the smallest n of its zone; code 4 uses data along the smallest m and smallest n of its zone.

COMPLETE 10X10 DOMAIN

USING CODE 1.

```
    PROP   TF-033   GROUND   SHOCK   STUDIES    CODE 1

   A          BEE         RHO      DELT           M          N

903889   7 238969-02 150000-03 200000-03 100000   2 100000   2

   H          K           EO         BETA      DELTA      ALPHA

222000   1 686000   4 214000   5 000000     100000-08 000000

SIGO       BEGIN       ANS           B          C

500000   2-500000     100000   1 216002   5 180001   1


   M          N           T           X          E          V          SIGMA


000000     000000      000000    000000     231480-02-277777   2 500000   2
000000     100000   1 100000-03 120000   1 212557-02-255070   2 459127   2
000000     200000   1 200000-03 240001   1 196766-02-236121   2 425019   2
000000     300000   1 300000-03 360001   1 183368-02-220043   2 396079   2
000000     400000   1 400000-03 480002   1 171843-02-206212   2 371184   2
000000     500000   1 500000-03 600002   1 161813-02-194176   2 349518   2
000000     600000   1 600000-03 720003   1 152996-02-183596   2 330475   2
000000     700000   1 700000-03 840003   1 145180-02-174217   2 313591   2
000000     800000   1 800000-03 960003   1 138198-02-165838   2 298510   2
000000     900000   1 900000-03 108000   2 131920-02-158304   2 284949   2
000000     100000   2 100000-02 120000   2 126241-02-151490   2 272683   2


100000   1 100000   1 200000-03 000000     310978-02-321195   2 500000   2
100000   1 200000   1 300000-03 120000   1 283534-02-296726   2 467426   2
100000   1 300000   1 400000-03 240001   1 260629-02-275758   2 438797   2
100000   1 400000   1 500000-03 360001   1 241226-02-257606   2 413484   2
100000   1 500000   1 600000-03 480002   1 224580-02-241749   2 390970   2
100000   1 600000   1 700000-03 600002   1 210146-02-227784   2 370830   2
100000   1 700000   1 800000-03 720003   1 197511-02-215396   2 352719   2
100000   1 800000   1 900000-03 840003   1 186359-02-204333   2 336352   2
100000   1 900000   1 100000-02 960003   1 176445-02-194396   2 321493   2
100000   1 100000   2 110000-02 108000   2 167574-02-185421   2 307944   2


200000   1 200000   1 400000-03 000000     384089-02-355553   2 500000   2
200000   1 300000   1 500000-03 120000   1 350227-02-330727   2 473202   2
200000   1 400000   1 600000-03 240001   1 321642-02-308934   2 448734   2
200000   1 500000   1 700000-03 360001   1 297221-02-289697   2 426407   2
200000   1 600000   1 800000-03 480002   1 276141-02-272625   2 406019   2
200000   1 700000   1 900000-03 600002   1 257781-02-257395   2 387374   2
200000   1 800000   1 100000-02 720003   1 241662-02-243741   2 370287   2
200000   1 900000   1 110000-02 840003   1 227408-02-231441   2 354595   2
200000   1 100000   2 120000-02 960003   1 214723-02-220313   2 340149   2
```

300000	1	300000	1	600000-03	000000		451328-02-383640	2	500000	2
300000	1	400000	1	700000-03	120000	1	412734-02-359208	2	477472	2
300000	1	500000	1	800000-03	240001	1	379712-02-337303	2	456285	2
300000	1	600000	1	900000-03	360001	1	351191-02-317622	2	436460	2
300000	1	700000	1	100000-02	480002	1	326356-02-299895	2	417963	2
300000	1	800000	1	110000-02	600002	1	304572-02-283882	2	400730	2
300000	1	900000	1	120000-02	720003	1	285339-02-269371	2	384683	2
300000	1	100000	2	130000-02	840003	1	268255-02-256182	2	369738	2

400000	1	400000	1	800000-03	000000		513165-02-407119	2	500000	2
400000	1	500000	1	900000-03	120000	1	471185-02-383494	2	480766	2
400000	1	600000	1	100000-02	240001	1	434784-02-361917	2	462240	2
400000	1	700000	1	110000-02	360001	1	402989-02-342221	2	444541	2
400000	1	800000	1	120000-02	480002	1	375038-02-324235	2	427726	2
400000	1	900000	1	130000-02	600002	1	350325-02-307794	2	411809	2
400000	1	100000	2	140000-02	720003	1	328358-02-292743	2	396779	2

500000	1	500000	1	100000-02	000000		570034-02-427062	2	500000	2
500000	1	600000	1	110000-02	120000	1	525745-02-404472	2	483388	2
500000	1	700000	1	120000-02	240001	1	486855-02-383498	2	467066	2
500000	1	800000	1	130000-02	360001	1	452512-02-364077	2	451195	2
500000	1	900000	1	140000-02	480002	1	422033-02-346116	2	435879	2
500000	1	100000	2	150000-02	600002	1	394861-02-329516	2	421178	2

600000	1	600000	1	120000-02	000000		622336-02-444207	2	500000	2
600000	1	700000	1	130000-02	120000	1	576599-02-422768	2	485524	2
600000	1	800000	1	140000-02	240001	1	535965-02-402570	2	471057	2
600000	1	900000	1	150000-02	360001	1	499705-02-383620	2	456773	2
600000	1	100000	2	160000-02	480002	1	467227-02-365891	2	442798	2

700000	1	700000	1	140000-02	000000		670435-02-459084	2	500000	2
700000	1	800000	1	150000-02	120000	1	623943-02-438848	2	487296	2
700000	1	900000	1	160000-02	240001	1	582185-02-419527	2	474410	2
700000	1	100000	2	170000-02	360001	1	544555-02-401182	2	461515	2

800000	1	800000	1	160000-02	000000		714671-02-472089	2	500000	2
800000	1	900000	1	170000-02	120000	1	667977-02-453065	2	488786	2
800000	1	100000	2	180000-02	240001	1	625611-02-434677	2	477261	2

900000	1	900000	1	180000-02	000000		755354-02-483527	2	500000	2
900000	1	100000	2	190000-02	120000	1	708898-02-465697	2	490053	2

100000	2	100000	2	200000-02	000000		792768-02-493640	2	500000	2

COMPLETE 10X10 DOMAIN
USING CODES 1, 2, 3, 4.

```
PROB  TF-033  GROUND  SHOCK  STUDIES   CODE 1

   A        BEE         RHO       DELT         M          N

903889  7 238969-02 150000-03 200000-03 300000 01 300000 01

   H         K          EO        BETA     DELTA      ALPHA

222000  1 686000  4 214000  5 000000    100000-08 000000

SIGO      BEGIN      ANS         B         C

500000  2-500000    100000  1 216002  5 180001  1

   M         N          T         X          E        V          SIGMA

000000     000000     000000    000000    231480-02-277777  2 500000  2
000000     100000   1 100000-03 120000  1 212557-02-255070  2 459127  2
000000     200000   1 200000-03 240001  1 196766-02-236121  2 425019  2
000000     300000   1 300000-03 360001  1 183368-02-220043  2 396079  2

100000  1 100000  1 200000-03 000000    310978-02-321195  2 500000  2
100000  1 200000  1 300000-03 120000  1 283534-02-296726  2 467426  2
100000  1 300000  1 400000-03 240001  1 260629-02-275758  2 438797  2

200000  1 200000  1 400000-03 000000    384089-02-355553  2 500000  2
200000  1 300000  1 500000-03 120000  1 350227-02-330727  2 473202  2

300000  1 300000  1 600000-03 000000    451328-02-383640  2 500000  2
```

PROB TF-033 GROUND SHOCK STUDIES CODE 2

A	BEE	RHO	DELT	M	N
903889 7	238969-02	150000-03	200000-03	400000 1	700000 1

H	K	EO	BETA	DELTA	ALPHA
222000 1	686000 4	214000 5	000000	100000-08	000000

SIGO	BEGIN	ANS	B	C
500000	2-500000	100000 1	216002 5	180001 1

M	N	T	X	E	V	SIGMA
400000 1	400000 1	800000-03	000000	513165-02	-407119 2	500000 2
400000 1	500000 1	900000-03	120000 1	471185-02	-383494 2	480765 2
400000 1	600000 1	100000-02	240001 1	434784-02	-361917 2	462240 2
400000 1	700000 1	110000-02	360001 1	402989-02	-342221 2	444541 2
500000 1	500000 1	100000-02	000000	570035-02	-427062 2	500000 2
500000 1	600000 1	110000-02	120000 1	525745-02	-404472 2	483388 2
500000 1	700000 1	120000-02	240001 1	486855-02	-383498 2	467066 2
600000 1	600000 1	120000-02	000000	622336-02	-444207 2	500000 2
600000 1	700000 1	130000-02	120000 1	576599-02	-422768 2	485524 2
700000 1	700000 1	140000-02	000000	670436-02	-459083 2	500000 2

PROP TF-033 GROUND SHOCK STUDIES CODE 2

A		BEE	RHO	DELT	M		N	
903889	7	238969-02	150000-03	200000-03	800000	1	100000	2

H		K		E0		BETA	DELTA	ALPHA
222000	1	686000	4	214000	5	000000	100000-08	000000

SIGO		BEGIN	ANS		B		C	
500000	2	-500000	100000	1	216002	5	180001	1

M		N		T	X		E	V		SIGMA	
800000	1	800000	1	160000-02	000000		714671-02	-472089	2	500000	2
800000	1	900000	1	170000-02	120000	1	667976-02	-453065	2	488786	2
800000	1	100000	2	180000-02	240001	1	625610-02	-434677	2	477261	2
900000	1	900000	1	180000-02	000000		755353-02	-483527	2	500000	2
900000	1	100000	2	190000-02	120000	1	708898-02	-465697	2	490053	2
100000	2	100000	2	200000-02	000000		792768-02	-493640	2	500000	2

PROB TF-033 GROUND SHOCK STUDIES CODE 3

A		BEE	RHO	DELT	M		N	
903889	7	238969-02	150000-03	200000-03	300000	1	100000	2

H		K		EO		BETA	DELTA	ALPHA
222000	1	686000	4	214000	5	000000	100000-08	000000

SIGO	BEGIN	ANS	
500000	2-500000	100000	1

M		N		T	X		E V		SIGMA	
000000		300000	1	300000-03	360001	1	183368-02-220043	2	396079	2
000000		400000	1	400000-03	480001	1	171843-02-206213	2	371184	2
000000		500000	1	500000-03	600002	1	161813-02-194176	2	349519	2
000000		600000	1	600000-03	720002	1	152997-02-183597	2	330475	2
000000		700000	1	700000-03	840003	1	145180-02-174217	2	313592	2
000000		800000	1	800000-03	960003	1	138198-02-165839	2	298510	2
000000		900000	1	900000-03	108000	2	131920-02-158305	2	284949	2
000000		100000	2	100000-02	120000	2	126241-02-151490	2	272683	2
100000	1	300000	1	400000-03	240001	1	260629-02-275758	2	438797	2
100000	1	400000	1	500000-03	360001	1	241225-02-257606	2	413484	2
100000	1	500000	1	600000-03	480002	1	224580-02-241749	2	390970	2
100000	1	600000	1	700000-03	600002	1	210146-02-227784	2	370830	2
100000	1	700000	1	800000-03	720003	1	197511-02-215396	2	352720	2
100000	1	800000	1	900000-03	840003	1	186359-02-204333	2	336352	2
100000	1	900000	1	100000-02	960004	1	176445-02-194396	2	321493	2
100000	1	100000	2	110000-02	108000	2	167574-02-185421	2	307944	2
200000	1	300000	1	500000-03	120000	1	350227-02-330727	2	473202	2
200000	1	400000	1	600000-03	240000	1	321642-02-308934	2	448734	2
200000	1	500000	1	700000-03	360001	1	297220-02-289697	2	426407	2
200000	1	600000	1	800000-03	480001	1	276141-02-272625	2	406019	2
200000	1	700000	1	900000-03	600002	1	257781-02-257395	2	387373	2
200000	1	800000	1	100000-02	720002	1	241662-02-243741	2	370287	2
200000	1	900000	1	110000-02	840003	1	227408-02-231441	2	354595	2
200000	1	100000	2	120000-02	960003	1	214723-02-220313	2	340149	2
300000	1	300000	1	600000-03	000000		451328-02-383640	2	500000	2
300000	1	400000	1	700000-03	120000	1	412733-02-359208	2	477471	2
300000	1	500000	1	800000-03	240001	1	379712-02-337303	2	456285	2
300000	1	600000	1	900000-03	360001	1	351191-02-317622	2	436460	2
300000	1	700000	1	100000-02	480002	1	326356-02-299895	2	417963	2
300000	1	800000	1	110000-02	600002	1	304572-02-283881	2	400730	2

300000	1	900000	1	120000-02	720003	1	285339-02-269371	2	384683	2
300000	1	100000	2	130000-02	840003	1	268255-02-256182	2	369738	2

PROB TF-033 GROUND SHOCK STUDIES CODE 4

A		BEE	RHO	DELT	M		N	
903889	7	238969-02	150000-03	200000-03	700000	1	100000	2

H		K		EO		BETA	DELTA	ALPHA
222000	1	686000	4	214000	5	000000	100000-08	000000

SIGO	BEGIN	ANS		B		C	
500000	2-500000	100000	1	216002	5	180001	1

M		N		T	X		E	V		SIGMA	
400000	1	700000	1	110000-02	360001	1	402989-02	-342221	2	444541	2
400000	1	800000	1	120000-02	480001	1	375038-02	-324235	2	427725	2
400000	1	900000	1	130000-02	600002	1	350324-02	-307794	2	411809	2
400000	1	100000	2	140000-02	720002	1	328358-02	-292743	2	396779	2
500000	1	700000	1	120000-02	240001	1	486855-02	-383498	2	467066	2
500000	1	800000	1	130000-02	360001	1	452511-02	-364077	2	451195	2
500000	1	900000	1	140000-02	480002	1	422032-02	-346116	2	435879	2
500000	1	100000	2	150000-02	600002	1	394861-02	-329516	2	421178	2
600000	1	700000	1	130000-02	120000	1	576599-02	-422768	2	485524	2
600000	1	800000	1	140000-02	240000	1	535964-02	-402570	2	471056	2
600000	1	900000	1	150000-02	360001	1	499705-02	-383620	2	456773	2
600000	1	100000	2	160000-02	480001	1	467227-02	-365891	2	442798	2
700000	1	700000	1	140000-02	000000		670435-02	-459084	2	500000	2
700000	1	800000	1	150000-02	120000	1	623943-02	-438848	2	487296	2
700000	1	900000	1	160000-02	240001	1	582185-02	-419527	2	474410	2
700000	1	100000	2	170000-02	360001	1	544555-02	-401182	2	461515	2

ACKNOWLEDGEMENT

The author wishes to express appreciation to Messrs. Thompson and R. C. Makino for their technical assistance.

Millicent M. Beck

MILLICENT M. BECK

REFERENCES

1. Thompson, Andrew A. Preliminary Plane Wave Studies in the Earth Shock Tube. Ballistic Research Laboratories Technical Note No. 1343, September 1960.

2. Thompson, Andrew A. Soil Shock Tube Techniques, Part - 1. Ballistic Research Laboratories Technical Note No. 1396, March 1961.

3. Design and Instrumentation of an Earth Shock Tube, Atlantic Research Corporation Contract No. DA-36-034-ORD-3116RD, Progress Reports 1-18, 1961-62.

4. Mercado, E. J. Stress Propagation in Non-linear Visco-Elastic Materials. Technical Report No. 3, Rensselaer Polytechnic Institute, May 1, 1962.

5. Mercado, E. J. Stress Propagation in Non-linear Visco-Elastic Materials. Technical Report No. 4, Rensselaer Polytechnic Institute, September 14, 1962.

6. Mercado, E. J. Stress Propagation in Non-linear Visco-Elastic Materials. Technical Report No. 5, Rensselaer Polytechnic Institute, January 31, 1963.

7. Malvern, L. E. Plastic Wave Propagation in a Bar of Material Exhibiting a Strain - Rate Effect. Quarterly of Appl. Math., Vol. 8, No. 4, January 1950.

8. Malvern, L. E. The Propagation of Longitudinal Waves of Plastic Deformation in a Bar of Material Exhibiting a Strain - Rate Effect. Trans. ASME, Jour. Appl. Mech., Vol. 18, page 203, 1951.

9. Osgood, W. R. Stress-Strain Formulas. Jour. of the Aero. Sciences, pages 45-48, January 1946.

10. Mercado, E. J. Stress Propagation in Non-linear Viscoelastic Materials. A Thesis Submitted to the Faculty of the Department of Geology, Rensselaer Polytechnic Institute, March 1963.

11. Campbell, L. W. and Beck, G. A. The FORAST Programming Language for ORDVAC and BRLESC, Ballistic Research Laboratories Report No. 1172, August 1962.

DISTRIBUTION LIST

No. of Copies	Organization
20	Commander Defense Documentation Center ATTN: TIPCR Cameron Station Alexandria, Virginia 22314
1	Director Advanced Research Projects Agency Department of Defense Washington, D. C. 20301
5	Chief Defense Atomic Support Agency Washington, D. C. 20301
1	Commanding General Field Command Defense Atomic Support Agency P. O. Box 5100 Albuquerque, New Mexico
1	Director National Security Agency ATTN: R/D 36, Chief, Engineering Research Division Fort George G. Meade, Maryland 20755
1	Commanding General U. S. Army Materiel Command ATTN: AMCRD-RP-B Washington, D. C. 20315
1	Commanding Officer Frankford Arsenal ATTN: Pitman-Dunn Laboratories Library Branch, 0270, Bldg. 40 Philadelphia, Pennsylvania 19137
1	Commanding Officer Picatinny Arsenal ATTN: Feltman Research and Engineering Laboratories Dover, New Jersey 07801
1	Commanding Officer Watertown Arsenal Watertown, Massachusetts 02172
1	Commanding General U. S. Army Missile Command Redstone Arsenal, Alabama 35809
1	Commanding General U. S. Army Munitions Command Dover, New Jersey 07801
1	Commanding General Land Locomotion Research Laboratory U. S. Army Tank-Automotive Center Warren, Michigan 48090
1	Commanding General U. S. Army Weapons Command Rock Island, Illinois 61200
1	Commanding General White Sands Missile Range New Mexico 88002
1	Director Major Item Supply Management Agency Letterkenny Army Depot Chambersburg, Pennsylvania 17201
1	Commanding General U. S. Army Chemical Corps Research & Development Command Washington 25, D. C.
1	Commanding General U. S. Army Chemical Warfare Laboratories Edgewood Arsenal, Maryland 21040

DISTRIBUTION LIST

No. of Copies	Organization
1	Commanding General Chemical Corps Materiel Command ATTN: David T. Shepard, Director Data Processing Center Edgewood Arsenal, Maryland 21040
1	Commanding General U. S. Army Chemical Center Corps Engineering Command Edgewood Arsenal, Maryland 21040
1	Director U. S. Army Nuclear Defense Laboratory Edgewood Arsenal, Maryland 21040
1	Commanding Officer Operations Research Group Edgewood Arsenal, Maryland 21040
1	Director U. S. Army Chemical Corps Quality Assurance Technical Agency Edgewood Arsenal, Maryland 21040
1	Commanding Officer U. S. Army Chemical Research and Development Laboratories Edgewood Arsenal, Maryland 21040
1	Chairman U. S. Army Chemical Corps Technical Committee Edgewood Arsenal, Maryland 21040
1	Commanding General U. S. Army Chemical Corps Proving Ground Dugway Proving Ground Dugway, Utah 84022
1	Director U. S. Army Biological Laboratories Fort Detrick, Maryland 21701
1	Commanding Officer U. S. Army Corps of Engineers Army Reactors Group Fort Belvoir, Virginia 22060
1	Commanding Officer U. S. Army Corps of Engineers Polar Research & Development Center Fort Belvoir, Virginia 22060
2	Commanding General U. S. Army Engineering Research & Development Laboratories ATTN: Dr. T. G. Walsh Mr. V. M. Davis - Mine Warfare Branch Fort Belvoir, Virginia 22060
1	Commanding Officer U. S. Army Corps of Engineers Army Reactors Group Germantown, Maryland
3	Director Waterways Experiment Station ATTN: Mr. G. L. Arbuthnot Mr. William Flathau Mr. Robert Cunny Box 631 Vicksburgh, Mississippi
1	U. S. Army Corps of Engineers Special Assistant for Nuclear Power Building T-7 Washington 25, D. C.
2	Chief of Engineers ATTN: Maj. Maurice K. Durtz Mr. Martin Kirkpatrick Washington 25, D. C.

DISTRIBUTION LIST

No. of Copies	Organization
1	Director U. S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory 1215 Washington Avenue Wilmette, Illinois
1	Director U. S. Army Medical Research and Nutrition Laboratory Denver, Colorado
1	Commanding Officer U. S. Army Medical Research and Development Command Washington 25, D. C.
1	Commanding Officer U. S. Army Medical Unit Fort Detrick, Maryland 21701
1	Director U. S. Army Medical Research Laboratory Fort Knox, Kentucky 40120
1	Commanding Officer U. S. Army Signal Engineering Agency Arlington Hall Station Arlington, Virginia 22212
1	Commanding General U. S. Army Signal Missile Support Agency White Sands Missile Range New Mexico 88002
1	Commanding Officer U. S. Army Signal Intelligence Agency Arlington Hall Station Arlington, Virginia 22212
1	Commanding Officer U. S. Army Signal Avionics Field Office P. O. Box 209 St. Louis 66, Missouri
1	Commandant U. S. Army Signal Corps School ATTN: Officer Department Fort Monmouth, New Jersey 07703
1	Chief Signal Officer ATTN: Mr. G. H. McClurg - SIGRD - 6 Department of the Army Washington 25, D. C.
1	Commanding General U. S. Army Electronic Proving Ground Fort Huachuca, Arizona 85613
1	Commanding Officer U. S. Army Electronics Research Unit P. O. Box 205 Mountain View, California 94042
1	Commanding General U. S. Army Electronics Research and Development Laboratory ATTN: Data Equipment Branch Fort Monmouth, New Jersey 07703
1	Commanding General U. S. Army Electronics Command ATTN: AMSEL-CB Fort Monmouth, New Jersey 07703
1	Director U. S. Army Quartermaster Research and Engineering Field Evaluation Agency ATTN: TD 10-5411-02 Fort Lee, Virginia 23801

DISTRIBUTION LIST

No. of Copies	Organization
[illegible]	Commanding General Quartermaster Research & Development Command ATTN: Dr. John M. Davies Mr. W. Zagieboylo Natick, Massachusetts
1	Commanding Officer U. S. Army Transportation Materiel Command 12th and Spruce Streets St. Louis, Missouri
1	Commanding General U. S. Army Transportation Research Command Fort Eustis, Virginia 23604
1	Commanding General U. S. Continental Army Command Fort Monroe, Virginia 23351
1	Commandant U. S. Army Artillery & Guided Missile School Fort Sill, Oklahoma 73503
1	Commandant U. S. Army Guided Missile School ATTN: Redstone Section, BM Branch, FAM Division Redstone Arsenal, Alabama 35809
1	Army Research Office 3045 Columbia Pike Arlington, Virginia
1	Commanding Officer Army Research Officer (Durham) Box CM, Duke Station Durham, North Carolina 27706
1	Commandant Command & General Staff College ATTN: Computing Facility Fort Leavenworth, Kansas 66027
1	Commanding Officer U. S. Army Communications Agency The Pentagon Washington 25, D. C.
1	Commanding General ATTN: Computing Facility Fort George G. Meade, Maryland 20755
1	Chief of Research & Development Department of the Army Washington, D. C. 20310
1	Professor of Ordnance U. S. Military Academy West Point, New York 10996
5	Chief, Bureau of Naval Weapons ATTN: DLI-3 (3 cys) RRE Department of the Navy Washington, D. C. 20360
[illegible]	Commander U. S. Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland
1	Commanding Officer U. S. Naval Ordnance Laboratory Corona, California 91720
[illegible]	Commander U. S. Naval Ordnance Test Station ATTN: Technical Library Editorial Section China Lake, California 93557
1	Library U. S. Naval Postgraduate School ATTN: Technical Reports Section Monterey, California

DISTRIBUTION LIST

No. of Copies	Organization
1	Director U. S. Naval Research Laboratory ATTN: Code 492 Washington, D. C. 20390
2	Director U. S. Naval Research Laboratory Anacostia Station Washington 20, D. C.
1	Commander U. S. Naval Weapons Laboratory Dahlgren, Virginia 22448
2	Chief of Naval Research ATTN: Code 118 Department of the Navy Washington, D. C. 20360
1	Chief of Naval Operations ATTN: Op-36 Department of the Navy Washington, D. C. 20360
1	Chief, Bureau of Ships ATTN: Computing Facility Department of the Navy Washington, D. C. 20360
1	Chief, Bureau of Yards and Docks Department of the Navy Washington, D. C. 20360
2	Commander U. S. Naval Missile Center ATTN: Simulation Branch Systems Department Range Operations Department, Code 3280 Point Mugu, California 93041
1	Commander Naval Engineering Experiment Station ATTN: Applied Math Office, Code 502 Annapolis, Maryland
1	Commanding Officer U. S. Naval Air Development Center Johnsville, Pennsylvania
1	Commanding Officer Naval Air Test Center ATTN: Armament Test U. S. Naval Air Station Patuxent River, Maryland
1	Commanding Officer & Director U. S. Naval Radiological Defense Laboratory San Francisco 24, California
1	Director U. S. Naval Supersonic Laboratory Massachusetts Institute of Technology ATTN: Computer Facility 560 Memorial Drive Cambridge, Massachusetts
1	Superintendent U. S. Naval Academy ATTN: Weapons Department Annapolis, Maryland
1	Officer/in/Charge Naval Civil Engineering Research & Evaluation Laboratory Naval Station Port Hueneme, California
1	Commanding Officer Fleet Operations Control Center U. S. Pacific Fleet F. N. Quinn Navy No. 509 Fleet Post Office San Francisco, California

DISTRIBUTION LIST

No. of Copies	Organization
1	Commanding Officer and Director David W. Taylor Model Basin ATTN: Structural Mechanics Division Washington, D. C. 20007
1	AFSC (SCT) Andrews Air Force Base Washington, D. C. 20331
1	AFFTC (FTFSE) Edwards Air Force Base California 93523
1	APGC (PGAPI) Eglin Air Force Base Florida 32542
1	AFMSD Holloman Air Force Base New Mexico 88330
1	AFWL (SWRS) Kirtland Air Force Base New Mexico 87117
1	AFCRL (CRZ) L. G. Hanscom Field Bedford, Massachusetts 01731
1	TAC (DCRS) Langley Air Force Base Virginia 23365
1	AUL (3T-AUL-60-118) Maxwell Air Force Base Alabama 36112
1	BSD Norton Air Force Base California 92409
1	AEDC Tullahoma, Tennessee 37389
1	AFIT Wright-Patterson Air Force Base Ohio 45433
1	RTD SEH Wright-Patterson Air Force Base Ohio 45433
1	Hq., USAF (AFAAC) Washington, D. C. 20330
3	Hq., USAF (AFADA) Washington, D. C. 20330
2	Hq., USAF (AFNIN 3) Washington, D. C. 20330
1	Hq., USAF (AFRDC) Washington, D. C. 20330
1	Hq., USAF, AFXOP (AFTAC) Washington, D. C. 20330
1	USAFA USAF Academy Colorado 80840
1	SSD AF Unit Post Office Los Angeles, California 9045
1	Clim Cen USAF Annex 2 225 D Street, S. E. Washington, D. C.
1	Director, Project RAND Department of the Air Force 1700 Main Street Santa Monica, California 90406
1	Central Intelligence Agency OCR/Library/ILS ATTN: Norman E. Hill, Code 163 Washington, D. C. 20505

DISTRIBUTION LIST

No. of Copies	Organization
1	Director National Aeronautics and Space Administration ATTN: Mr. R. E. Liettell 1520 H Street, N. W. Washington, D. C. 20546
1	Director National Aeronautics and Space Administration Flight Research Center ATTN: Computer Facility Box 273 Edwards, California
2	Director National Aeronautics and Space Administration Goddard Space Flight Center ATTN: Tracking & Data Systems I. Mortimer Datz - Computer Operations Branch, Data Systems Division Anacostia Naval Station Washington 25, D. C.
1	Director National Aeronautics and Space Administration Lewis Research Center ATTN: Computer Facility Cleveland Airport Cleveland, Ohio
1	Federal Aviation Agency National Aviation Facilities Experimental Station ATTN: Simulation & Computation Branch Atlantic City, New Jersey

No. of Copies	Organization
1	Federal Aviation Agency ATTN: Data Processing Branch - Aircraft Management Division Bureau of Flight Standards P. O. Box 1082 Oklahoma City, Oklahoma
1	Chief, Bureau of Mines Washington 25, D. C.
2	Director National Bureau of Standards ATTN: Mr. Paul Meissner Components & Technique Section - Data Processing Systems Division Dr. S. N. Alexander 232 Dynamometer Building Washington 25, D. C.
2	Director National Bureau of Standards National Applied Mathematics Laboratory ATTN: Miss Mary Stevens Dr. Franz L. Alt Computation Laboratory Washington 25, D. C.
1	U. S. Department of Commerce Bureau of Census ATTN: Computer Facility Federal Office Building No. 3 Suitland, Maryland
1	U. S. Atomic Energy Commission Military Applications Division 1901 Constitution Avenue, N. W. Washington 25, D. C.

DISTRIBUTION LIST

No. of Copies	Organization
1	Executive Secretary Military Liaison Committee to the Atomic Energy Commission 1901 Constitution Avenue, N. W. Washington, D. C.
1	Brookhaven National Laboratory ATTN: Computer Facility Upton, New York
1	Oak Ridge National Laboratory Mr. E. C. Long P. O. Box X Oak Ridge, Tennessee
2	Los Alamos Scientific Laboratory P. O. Box 1663 Los Alamos, New Mexico 87544
1	Sandia Corporation ATTN: Physics Division P. O. Box 5800 Albuquerque, New Mexico 87115
1	Research Analysis Corporation ATTN: Computer Facility 6935 Arlington Road Bethesda, Maryland Washington, D. C. 20014
1	Applied Physics Laboratory Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland
1	Jet Propulsion Laboratory ATTN: Computer Facility 4800 Oak Grove Drive Pasadena 3, California
1	Lawrence Radiation Laboratory P. O. Box 808 Livermore, California 94551
2	Ampex Computer Products Co. 9937 Jefferson Boulevard Culver City, California
1	Atlantic Research Corporation ATTN: Mr. R. C. Bryant Shirley Highway at Edsall Road Alexandria, Virginia
1	Datatrol Corporation Consulting and Programming Services ATTN: Mr. Cooper, Vice-President 8113A Fenton Street Silver Spring, Maryland
1	Engineering Research Associates Division of Remington Rand, Inc. 1902 W. Minneehaha Avenue St. Paul, Minnesota
1	General Mills Electronics Group 1000 16th Street, N. W. 306 Solar Building Washington 6, D. C.
1	International Business Machine Corporation Engineering Laboratory ATTN: John Ashley - Customer Executive Education Department San Jose, California
1	Raytheon Manufacturing Company P. O. Box 398 Bedford, Massachusetts

DISTRIBUTION LIST

No. of Copies	Organization
1	Remington Rand Univac Division of Sperry Rand Corporation ATTN: Mr. Sam Howry - Systems Analysis 1900 W. Allegheny Avenue St. Paul, Minnesota
1	Science Research Association, Inc. 259 East Erie Street ATTN: Mr. Don Shepherd, Project Director Chicago 11, Illinois
2	Technitrol Engineering Corporation 1952 E. Allegheny Avenue Philadelphia 34, Pennsylvania
1	United Research Services 1811 Trousdale Drive Burlingame, California
1	California Institute of Technology ATTN: R. B. Gilmore - Comptroller Pasadena, California
1	Columbia University Electronics Research Laboratories ATTN: G. S. Bodeen 632 West 125 Street New York 27, New York
1	Columbia University Lewis Cyclation Laboratory ATTN: Computer Facility Box 137 Irvington on Hudson, New York

No. of Copies	Organization
1	Cornell University ATTN: John W. Hastie - Coordinator of Research Ithaca, New York
1	Dartmouth College ATTN: Computation Center Hanover, New Hampshire
1	The George Washington University ATTN: Logistics Research Project 707 22nd Street, N. W. Washington 7, D. C.
1	Georgia Institute of Technology Engineering Experiment Station ATTN: Rich Electronic Computer Center Atlanta 13, Georgia
1	Harvard University Computation Laboratory Cambridge 38, Massachusetts
1	Illinois Institute of Technology Chicago, Illinois 60616
1	Indiana University ATTN: Research Computing Center Bloomington, Indiana
1	Iowa State University of Science and Technology Engineering Experiment Station ATTN: Robert M. Stewart, Jr. Cyclone Computer Lab Ames, Iowa
1	The Johns Hopkins University ATTN: Computation Center 34th and Charles Street Baltimore 18, Maryland

DISTRIBUTION LIST

No. of Copies	Organization
1	Lehigh University ATTN: Computer Facility Bethlehem, Pennsylvania
1	Marquette University ATTN: Computing Center 1515 West Wisconsin Avenue Milwaukee, Wisconsin
1	Massachusetts Institute of Technology Lincoln Laboratory ATTN: Computer Facility Lexington 73, Massachusetts
1	Massachusetts Institute of Technology ATTN: Digital Computer Laboratory Cambridge 39, Massachusetts
1	Michigan State University College of Engineering ATTN: Computer Lab East Lansing, Michigan
1	Missouri School of Mines and Metallurgy ATTN: Computer Facility Rolla, Missouri
1	Moore School of Electrical Engineering University of Pennsylvania Philadelphia 4, Pennsylvania
1	New York University College of Engineering ATTN: Computation & Statistical Lab University Heights New York 53, New York
1	Oklahoma State University The Computing Center ATTN: D. R. Shreve - Department of Mathematics Stillwater, Oklahoma
1	Oregon State College Department of Mathematics ATTN: W. E. Milne Corvallis, Oregon
1	Polytechnic Institute of Brooklyn ATTN: Mr. Warren Boes 333 Jay Street Brooklyn 1, New York
1	Princeton University Mathematics Department Princeton, New Jersey
1	Stanford Research Institute Menlo Park, California
1	Stanford University ATTN: Computation Center Stanford, California 94305
1	University of California 942 Hilldale Avenue Berkeley, California
1	University of Illinois Department of Mathematics ATTN: A. H. Taub Urbana, Illinois
1	University of Michigan Institute of Science and Technology ATTN: VESIAC, T. W. Caless Box 618 Ann Arbor, Michigan 48104

DISTRIBUTION LIST

No. of Copies	Organization
1	University of New Mexico ATTN: KAFB Shock Tube Facility Albuquerque, New Mexico 87106
1	Professor Bruce Charters Computing Laboratory Brown University Providence, Rhode Island
1	Professor W. H. Gardner, Jr. College of Engineering Durham, North Carolina
1	Professor J. Neils Thompson Civil Engineering Department University of Texas Austin 12, Texas
1	Dr. Walter Bleakney Princeton University Princeton, New Jersey
1	Dr. Otto LaPorte Engineering Research Institute University of Michigan Ann Arbor, Michigan 48104
1	Dr. N. M. Newmark 111 Talbot Laboratory University of Illinois Urbana, Illinois
1	Dr. Leonard Obert Applied Physics Division U. S. Bureau of Mines College Park 1, Maryland
1	Dr. L. H. Thomas Watson Scientific Computing Laboratory 612 W. 116th Street New York 27, New York
1	Dr. Robert V. Whitman Massachusetts Institute of Technology Cambridge 39, Massachusetts
1	Mr. Theodore Baumeister, III E. I. DuPont DeNemours, Co. Engineering Department Wilmington 98, Delaware
1	Mary Broadhead 12 Westfall Avenue Troy, New York
1	R. F. Jackson University of Delaware Newark, Delaware
1	University of Alberta Department of Mathematics ATTN: Professor John McNamee Edmonton, Alberta, Canada
4	Australian Group c/o Military Attache Australian Embassy 2001 Connecticut Avenue, N. W. Washington, D. C. 20008
10	The Scientific Information Office Defence Research Staff British Embassy 3100 Massachusetts Avenue, N. W. Washington, D. C. 20008
4	Defence Research Member Canadian Joint Staff 2450 Massachusetts Avenue, N. W. Washington, D. C. 20008

Aberdeen Proving Ground

Chief, TIB

Air Force Liaison Office
Marine Corps Liaison Office
Navy Liaison Office
CDC Liaison Office

D&PS Branch Library